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Abstract to Action: Targeted Learning System Theory Applied to Adaptive Flight Training

By

Travis H. Sheets, Maj, USAF
Matthew P. Elmore, Maj, USAF

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Advisor: Lt Col Peter A. Garretson
Dr. Andrew Stricker

Maxwell Air Force Base, Alabama

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Disclaimer

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To the Airmen of tomorrow:
Thank you for believing in the power of education and training to help grow the potential of humans. Thank you for trying to solve the Air Force problems that help people reach their true potential to protect our nation's freedom. Be adaptive and be aggressive. Always dream without barriers, think with purpose, act with conviction, and be willing to fail. Failure is the best teacher – our nation needs you.

"An expert is a person who has found out by his own painful experience all the mistakes that one can make in a very narrow field." - Niels Bohr[1]

Abstract

Education and training research that utilizes emerging technologies such as Virtual or Augmented Reality, Biosensing, and Artificial Intelligence often avoid broad approaches to maintain scientific rigor. This research study takes a practitioner's approach to transform abstract ideas into actionable options for the future of education and training. Using exploratory and applied design research, this study draws on pertinent scientific knowledge and fuses technologies in a novel way to create the overarching idea of the Targeted Learning Systems Theory (TLST). The TLST is an immersive, student-centered, multi-modal learning structure that empowers the learner and leverages emerging technology to provide high fidelity assessments and feedback. This paper examines educational structures, learning theories, emerging technologies, and uses a one-week trial with 40 subjects at Columbus, AFB to test the validity of the theory. The results indicated Cognitive, Kinesthetic, and Affective learning occurred. The average subject performance improvement was 205' (altitude control), 38 knots (airspeed control), and a 30% increase of procedural task completion with 1.5 hours of Virtual Reality Learning Environment (VRLE) training. The collection of biometric data also highlighted the value and possible impact of biosensing within future education and training structures. The TLST reimagines how the USAF could train and educate Airmen by creating flexible systems that capitalizes on human-machine integration to provide previously unforeseen value to the learner and the organization. It provides a vector to riposte the rising costs, changing requirements, and increasingly complex tasks plaguing education and training in USAF and is aligned with the 2018 AETC Strategic Plan.

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Introduction

"*The future belongs to the best-educated nation. Let it be ours." – VADM Hyman Rickover*[2]

The future is changing rapidly, and while no one can predict the future with any certainty, organizations can create adaptive learning structures to mitigate the risk imposed by change. The changes that threaten current United States Air Force (USAF) educational and training models are the rising cost, precipitous requirements, and the increasing complexity of tasks associated with preparing Airmen for future environments. These challenges foreshadow possible fractures in the traditional USAF training and education models unless new cost-effective, adaptive, and flexible ways are adopted. A current example of these trends are the rising cost and growing complexity of training tasks that prevent the USAF from surging pilot production in a time of dire need, such as a growing pilot shortage or a war with pilot attrition. In 2017, it took approximately seven years (including college), and $11 million to create a 5th Generation combat qualified pilot.[3] With the USAF facing a growing fighter pilot shortage already over 20%, it needs a new approach to education and training that can achieve the same caliber of graduates faster, while utilizing fewer resources.[4] This exploratory study uses a mixture of educational structures, learning theories, and technologies to create the Targeted Learning System Theory (TLST). The TLST scaffolds an integrated learning approach with an adaptive performance-based progression to change the value-paradigm of education and training for the USAF.

This research is framed around a practitioner's approach to creating actionable solutions. The intent is to identify new learning opportunities made available by recent technological advancements. Technology combined with the right educational structures developed with sound learning theories can help the USAF move a step closer to capitalizing on new means and ways of preparing, sustaining, and augmenting Airmen for future challenges.[5] As highlighted by the blue circles in Figure 1, this study falls under the categories of exploratory and generalized research. It focuses on theory development and identifying underlying constructs that align with results. A literature review of educational structure, theory, and technology, along with industry interviews, informed the development of the Targeted Learning System Theory (TLST). The researchers are both experienced aviators and educators and therefore chose flight training as a testbed for the TLST.

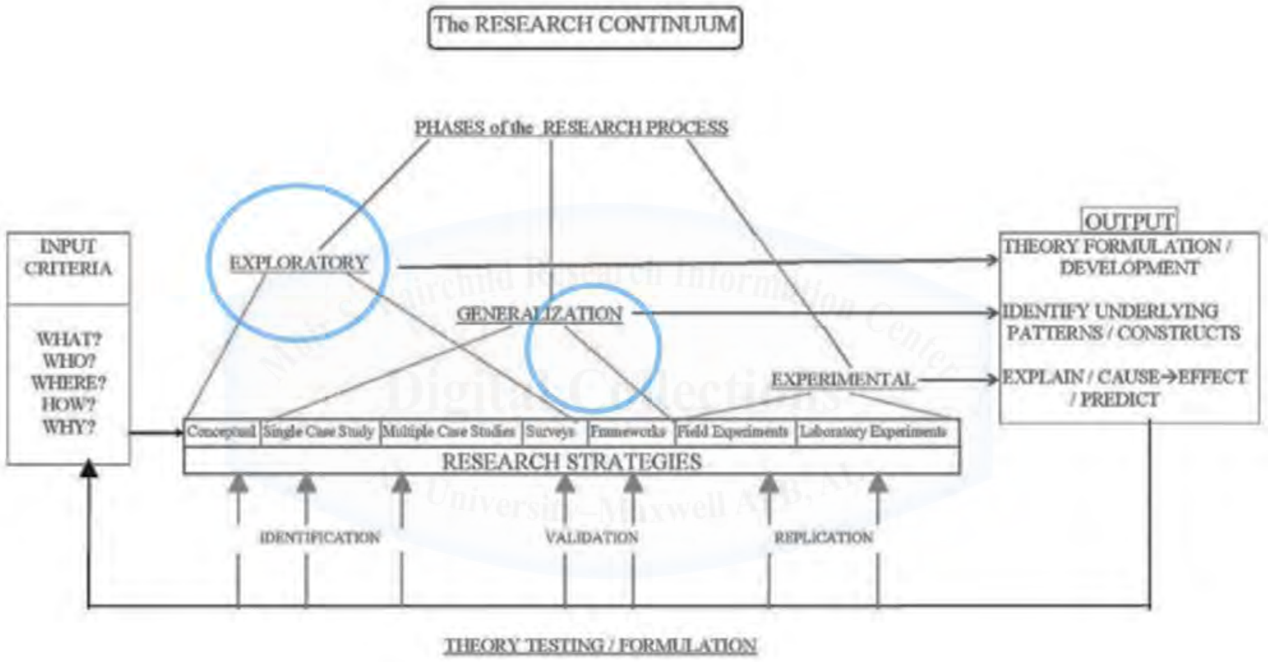

Figure 1. Research Continuum[6]

To test the applicability of the TLST to a specific task, three Adaptive Flight Trainers (AFT) were built using TLST, and a study was conducted at Columbus AFB, Mississippi to validate knowledge acquisition and skill creation. The study or trial specifically looked for indicators of cognitive and kinesthetic transference from an immersive virtual learning environment to a real-world physical environment. The AFT study measured forty subjects with various levels of flight experience using pre and post-training affective assessments, as well as pre and post-training evaluations in a T-6A flight simulator. In between the assessments subjects trained for 1.5 hours in the AFT. The comparison of pre and post evaluations determined the subject's performance improvement and is further discussed by sub-group in the Results section. Figure 2, provides a visual representation of the study. It describes how abstract constructs are used to observe the results and associate them with the hypothesis that the AFT (using the TLST design framework), is cost-effective, and enables cognitive, kinesthetic, and affective learning.

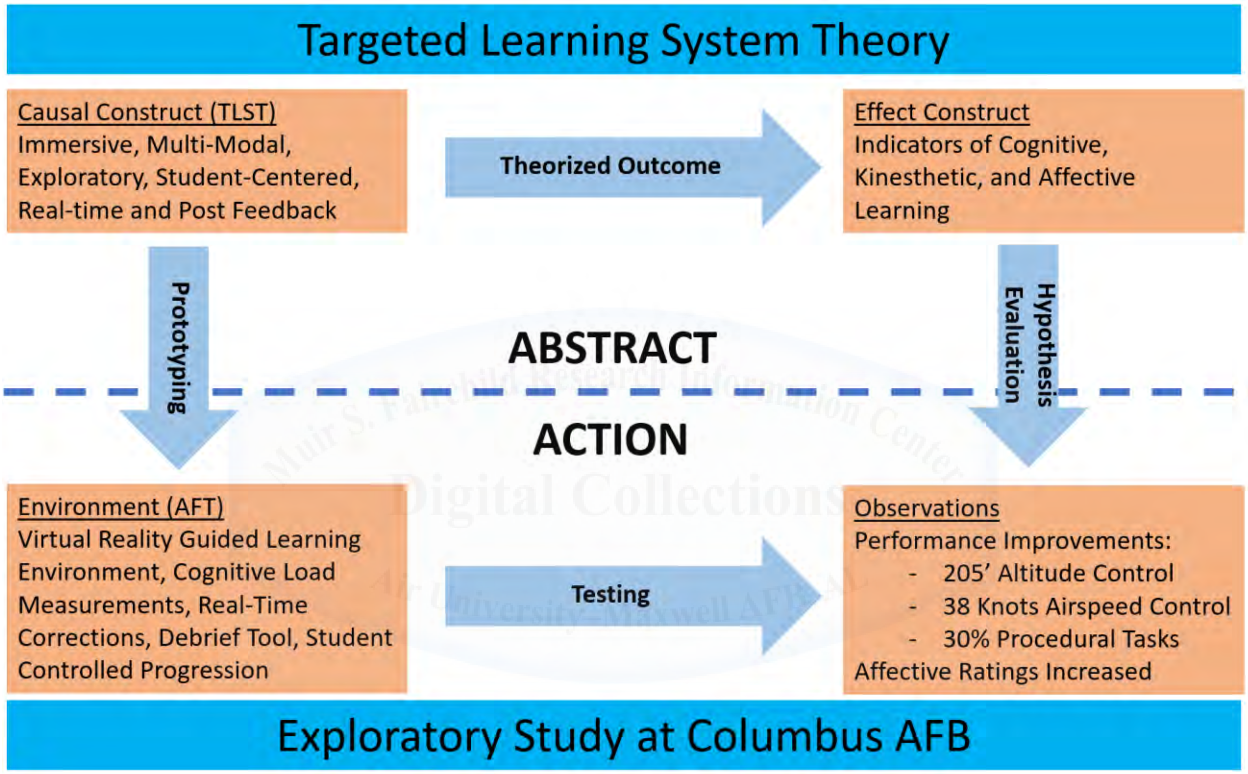

Figure 2. Visual Representation of the Study[7]

This research does not intend to solve the USAF education and training problems. The intention of this study is to explore structures, theories, and technology to find a new approach to learning that produces equal or better results at a lower cost with greater flexibility than the current USAF linear based systems. Although flight training was the task studied in this exploratory study, the TLST applies to other training and education requirements. To stay competitive in an increasingly complex and dynamic world, the USAF must take the lead and

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drive technology's integration into new education and training structures, or risk falling behind in an operating environment that is redefining requirements for success.

Educational Structures

"Our [education] system largely still adheres to the century-old, industrial-age factory model of education. A century ago, maybe it made sense to adopt seat-time requirements for graduation and pay teachers based on their educational credentials and seniority. But the factory model of education is the wrong model for the 21st century."– US Secretary of Education Arne Duncan[8]

A structure is an "arrangement of and relations between the parts or elements of something complex."[9] An educational or training structure is an arrangement of expectations, resources, rules, and curriculum requirements that provide the framework to create, mold, and shape the knowledge, skills, and behaviors of individuals. The purpose, priority, and relationships of the elements in the structure determine the character of a student's experience and provide a shell that guides a student's learning emotionally, cognitively, or kinesthetically. An educational or training structure can exist with an almost infinite number of variations. For this discussion, structures are imagined on a continuum, from fully instructional, rigid, and compliant, to student-centered, flexible, and experiential. Education and training structures are the shaping mechanisms that frame expectations, define the usage of resources, and order requirements to enable purposeful learning outcomes.

The educational and training structures utilized by the USAF are a product of the national educational structure whose creation began with the Pennsylvania Free School Act of 1834.[10] From 1834-1892, the United States developed a linear age-based model with rigid curriculum, and one-way instructional methods that are tied to one size fits all timelines.[11] The structure was based on the Prussian Model from the mid-1700's along with initiatives from Horace Mann in

1840 and the "Committee of Ten," led by Harvard President Charles Eliot in 1892.[12] The educational structures were "institutionally chartered to be universal, standardized, rational, and to conduct the socialization of the individual," providing free education to everyone.[13] The industrial structure of education was effective for a period, but the reality is socialization, standardization, and rational requirements are not the same as they were in the 19th and 20th century. Prussian structures along with the industrial revolution still heavily influence the expectations and requirements of educational and training structures used by K-12 schools, governments, and businesses in the 21st century.

The current USAF's traditional structures fail to connect with the next generation of digitally native learners, empower students, or prepare them with the cognitive elasticity necessary for volatile, uncertain, changing, connected, and ambiguous (VUCCA) environments. Digitally native learners accumulate information, communicate, and make sense of the world around them differently than students did decades ago. The internet of things and social media have made dramatic impacts on individual expectations in the western world. Students get frustrated and disengage from learning when archaic systems are not reliable, when they cannot digitally connect with peers, or the information they need is not readily available. Future structures need to ensure digital pathways are reliable, collaborative, and leverage the immersive ability technological advancements have provided. Using technology appropriately is the first step to help empower the student. Student empowerment is the personal motivation and authority the learner feels about their education or training. It relies on a student's self-awareness, curiosity, and purpose. To successfully empower students the structure should be student-centered and collaborative to promote informal learning, physiological safety, and belonging. Cognitive elasticity is a person's sensitivity and awareness to new paradigms, unanticipated information, or unsettling situations. It is a learned skill that combines a person's mental agility and emotional intelligence to think critically and creatively when there is no clear-cut solution. Learning opportunities that use cognitive elasticity teach people how to think, not just what to think, by letting them explore the underlying principles and relationships important within the context of a situation. Traditional models, as used in today's VUCCA environment, lack appeal to digital natives, fail to empower students, and do not place sufficient emphasis on cognitive elasticity, producing diminishing returns for the nation and the USAF.

Most structures today are so rigid they trade agility and creativity for compliance and standardization. They are bogged down in processes, oversight, and are partially blind to the exponential increase of technological change and the growing complexities surrounding them. These large lumbering industrial hierarchies and autocratic educational models struggle to recognize when new patterns emerge and rarely adapt to new challenges. The lack of adaptation and poor use of opportunities to forge cognitive elasticity is a dangerous problem for the USAF because it limits how we "bring the mind into form" and how we prepare Airmen to think when they tackle tomorrow's challenges.[14] As Admiral Rickover once said, "Most of our schools have lost sight of the fact that a well-trained mind can cope with many unforeseen problems. In a rapidly changing world, no one can foresee what future problems will have to be met."[15] The USAF must find a way to break the current dogmatic paradigm of structures that focus on filling the mind with facts "at the cost of absorbing fundamental principles," to produce a deeper, more rich understanding of the world around them.[16] Future educational and training structures should be aimed at breaking the inertia of these outdated models, capitalizing on disruptive technologies' ability to create personalized, flexible, adaptive learning systems that empower students to deal with change, complexity, and uncertainty.

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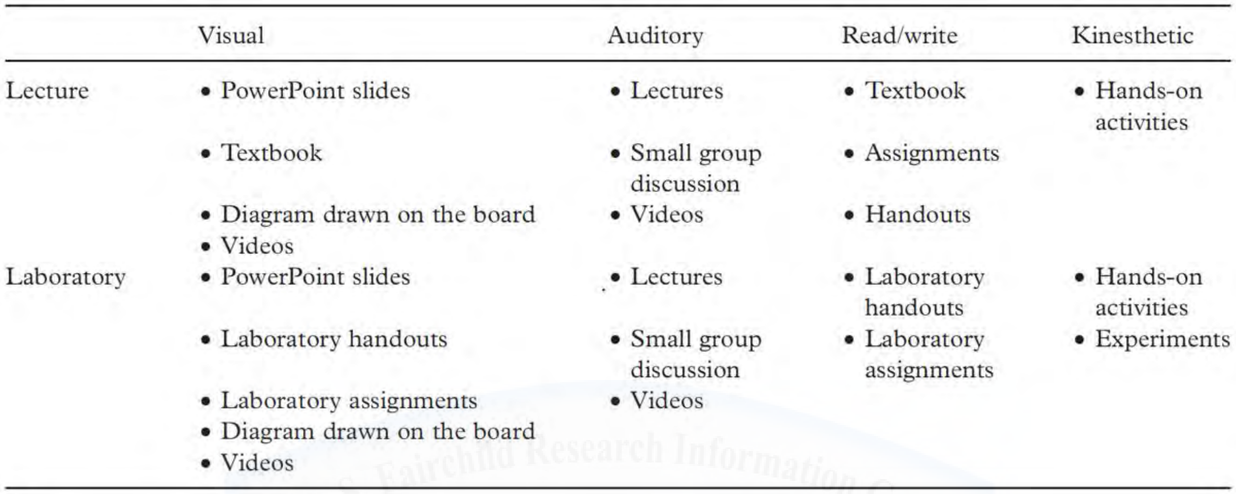
Although the structure is important, it is just one part of an effective educational and training environment. Like the body and frame of a car need an engine and wheels to be useful, the structure also needs the educational tools and a well-designed curriculum to ensure learning occurs. Understanding various learning styles is one way to create and integrate an effective curriculum and develop sound learning pathways into a structure. The VARK and Kolb learning models provide a framework of student learning styles along with applicability to learning in the virtual reality (VR) environment that helps to identify necessary pathways for multi-modal learning environments. Providing students with multiple learning pathways engage the learner, adds more value to the structure, and helps the organization make better use of time.

Learning Styles

The VARK Model

The VARK model, originally developed by Neil Fleming in 2006, has been used for years to identify a student's learning styles. The VARK Learning Style Inventory was specifically designed to identify learning style preference without cognitive, social factor, or personality biases.[17] Each of these four inventories is an information-processing model that describes a student's preferred approach to gathering and processing information.[18] The four learning inventories in the VARK model are the four ways information is presented to a student and how they process it; visual, aural, read/write, and kinesthetic. Visual learners assimilate information by looking at figures, graphs, videos, and using symbolic tools like flow charts or models. They also prefer to draw when teaching concepts to fellow students. On the other hand, aural learners prefer to listen to the information being presented vice taking notes and benefit from a discussion of concepts in the classroom. Read/write learners process information from printed text and assimilate it through taking notes. Hands on experience, practical application, and interaction with the learning are most effective for kinesthetic learners. They prefer experiential learning where they can touch and move in the environment.[19] The table below further expands on teaching and learning methods for each modality in the lecture or laboratory environments.



	Visual	Auditory	Read/write	Kinesthetic
Lecture	• PowerPoint slides	• Lectures	• Textbook	• Hands-on activities
	• Textbook	• Small group discussion	• Assignments	
	• Diagram drawn on the board • Videos	• Videos	• Handouts	
Laboratory	• PowerPoint slides	• Lectures	• Laboratory handouts	• Hands-on activities
	• Laboratory handouts	• Small group discussion	• Laboratory assignments	• Experiments
	• Laboratory assignments • Diagram drawn on the board • Videos	• Videos		

Table 1. Sensory modalities and corresponding teaching/learning methods[20]

The specific learning preference identifies the most "effective and efficient modality" for the learner to "perceive, process, store, and recall new information."[21] If learning were as simple as appealing to a student's preferred information processing model teaching would be simple. However, research indicates that most students are multimodal learners.

Prithiskumar and Michael conducted a study utilizing the VARK questionnaire to analyze learning styles for 91 students. The results demonstrated that 86.8% of the participants classified as multimodal learners, preferring two or more information-processing models when assimilating information. The most common were Aural-Kinesthetic (33%) and Aural-Read/Write (16.5%).[22] Studies conducted by Samarakoon et al. and Lujan et al. produced similar results with multimodal learning preferences identified in 69.9% and 63.8% of participants respectively.[23] What this indicates is the need for instructors to deliver information according to student preferences and that multiple modalities should be used to keep students' attention.[24] Although

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the modality of information has been documented to effect student learning, Hsieh, Mache, and Knudson went a step further, looking at whether or not it affects performance on examinations. Matching how the examination questions were presented to students based on their self-reported and evaluated learning style, they found no significant difference in test performance.[25] Regardless of whether the text-only test or visual format test aligned with their identified learning style, students showed similar levels of comprehension of biomechanical concepts.[26] More interestingly, the study identified that while most students articulated how they learned during the self-assessment, over half did not have a perception of their dominant preference as identified by the VARK questionnaire.[27] Therefore information within the learning environment should be presented using multiple modalities to appeal to a student's perceived and actual learning preferences.

Experiential Learning

Chen, Toh, and Ismail present another way of looking at learning styles in their article *Are learning styles relevant to virtual reality*? In this article, Kolb's working definition of experiential learning is described as the process of creating knowledge through the transformation of experience.[28] The experiential learning cycle is a loop of concrete experiences, observations, and reflections, forming abstract concepts and generalizations, and testing these concepts in new situations. Utilizing the experiential learning cycle, Kolb describes four learning styles focused on experience as opposed to methods of information being presented as described by the VARK model.

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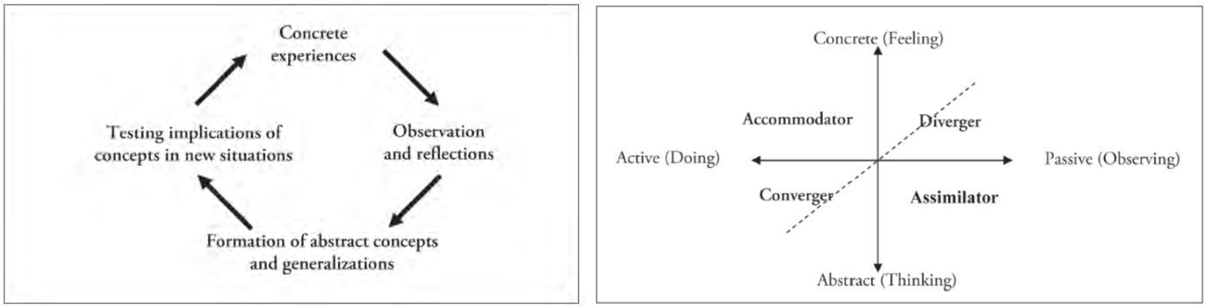

Figure 3. Kolb's experiential learning cycle (adapted from Hunsaker and Alessandra, 1986), and Kolb's Learning Style types (adapted from Kolb, 1999)[29]

As figure 3 demonstrates, an accommodator's dominant learning abilities come in the form of concrete experience, and active experimentation whereas an assimilator learns best through abstract conceptualization and reflective observation. A converger understands the experience through abstract conceptualization but transform through action. Finally, a diverger learns through concrete experience then reflect on the experience. The value of experience to all these learning styles makes VR a very effective learning tool because it can appeal to all learners.[30] This was demonstrated in Chen, Toh, and Ismail's test of assimilator and accommodator learners in the VR environment. They found that both types of learners showed a higher gain score in the guided VR environment. While this will be discussed further in a later section, the main point is that there was no negative effect on one learning style over the other. Subjects learn better when the material is presented in a manner that is consistent with their preferred learning style. In this case, one environment appealed to multiple types of learners.[31] Keeping the individual in mind and how they learn, the next question is how does the environment affect individual learning styles?

Learning in VR

Constructivists' educational theory states that learners should take an active role in their learning. It advocates for an experimental and experiential learning process similar to the learning cycle described by Kolb. Joining problem-solving and exploratory discovery allows learning to occur via a personalized student journey which promotes a deeper learning effect. VR Learning Environments (VRLE) offer important multi-modal (appealing to multiple learning modes to include visual, auditory, haptic, and tactile in some cases) and perceptual cues.[32] A key characteristic of a VRLE is that it is immersive, interactive and imaginative (I^3).[33] Regarding a student's interaction with and movement within the VRLE, it should provide an experience similar to what a user could expect to experience in the real world. It must provide realistic feedback and conform to the laws of physics. Finally, a user should always be able to navigate and orient themselves in the environment.[34] This last point is particularly important because of cognitive load theory.

The ability of a user to safely explore in a VRLE is one of the primary educational benefits, but the process of exploring has a cognitive load cost associated with it. Initially orienting oneself and remaining oriented utilizes mental resources which reduces the amount available to understand concepts being taught. If both the extraneous cognitive load required to orient in the environment, and the intrinsic cognitive load of the material being taught are high, it can exceed a user's mental resources thus reducing how much learning can occur. Reducing the amount of extraneous cognitive load by providing orientation guidance frees up a greater percentage of mental resources for learning.[35] Theoretically the interactive nature of VR and potential for high repetition of tasks can help improve knowledge retention. Additionally, providing an immersive and interactive environment can increase students' motivation to learn.[36] But is VR an effective educational tool? This question is answered by analyzing affective, cognitive, and kinesthetic learning in the VR environment.

In their meta-analysis of 69 studies, Merchant et al. discovered that VR is suitable for knowledge-based, abilities-based, and skill-based learning and as an instructional tool it was

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quite effective.[37] Research also shows that an I^3 VRLE has an affective influence on subjects. This is important because as described earlier, the VRLE needs to mimic the real world as closely as possible to ensure the similar experiences so deep learning can occur. In their study Won et al. measured subjects' anxiety levels to test the immersive qualities of a VRLE. Subjects were put in a virtual classroom with digital classmates. Subjects reported feeling social anxiety even though the digital classmates were not real. The social anxiety points to the fact that they obviously believed their digital peers were socially present.[38] The perceived reality of the virtual environment is a powerful, immersive tool that appeals to three of the four learning styles identified by Kolb. VR also can produce positive cognitive learning effects.

Spatial cognition is the ability to cognitively process the 3-D environment and use that information for various tasks, most often to locate something. As a result of immersive VRLEs, spatial cognition learning is enhanced. Rodrigues et al. trained subjects in a wayfinding task in a VRLE and then asked them to perform the task in the real world. They found that subjects could complete the VRLE trained task in the real world confirming a good transfer of spatial knowledge from VR to reality.[39] A VRLE was also used in a study to train underground coal miners in the completion of various tasks that have been statistically shown to be dangerous in the industry. Some of the tasks included removing undetonated explosives, drilling blasting holes, putting explosives together with blasting caps, and twelve others. In all cases, subjects performed better in the highly immersive VRLE and expressed a positive affective gain on their confidence and knowledge of the task procedures. One key limitation discovered was the lack of tactile feedback in the virtual environment.[40]

A looming question for this study is can VR training lead to kinesthetic transference in the real world? Ridderinkhof and Brass looked to tie in kinesthetic motor imagery, a cognitive

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activity common in the sports world, to motor expertise. Motor imagery allows an individual to perform and experience motor actions in mind.[41] They bring up its use in sports, however, this is a common practice at USAF UPT. Student pilots are regularly told to "chair fly," meaning close their eyes and visualize all the steps and actions they would take to execute a training maneuver. What they found is that kinesthetic motor imagery is effective at improving kinesthetic performance, particularly in the speed up of the neural activation during the preparatory planning stages that lead up to taking action. They further go on to say that to maximize the effectiveness of the motor imagery activity the subject must try as close as possible to match the actual performance in the physical, environmental, task, timing, learning, emotion, and perspective aspects.[42] VRLEs can match all seven of those aspects, creating the potential for significant kinesthetic learning.

Multiple studies have demonstrated the effectiveness of VRLEs promoting kinesthetic learning. Bailenson et al. used VR and traditional video recordings to train subjects to complete Tai Chi movements. They point out that VR affords more interactivity and provides more psychologically prominent and engaging sensory information.[43] What they found is that subjects reported they learned better in the VRLE, enjoyed the experience more, and felt the teacher was more credible. However, the objective data of their movements did not show significantly different performance than the video group. This was likely due to a lack of feedback being provided in the virtual environment, identified as a critical component of interactivity for learning.[44] Loukas et al. tested a similar principle using laparoscopic surgery (LS) skills training. They used both a traditional visual LS trainer and a VR trainer. Since LS requires the acquisition of fine psychomotor skills, they investigated the role of haptic feedback (or force feedback) on kinesthetic learning.[45] While they found that both learning environments were effective at

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learning the LS skills required, the lack of haptic feedback in the VR environment limited the level of performance that could be achieved.[46] However, another medically based study demonstrated that for intra-ocular surgery proficiency training, VR is effective, faster, and improved novice cataract surgeons' performance by 32%.[47] A key finding for both these studies is that training of kinesthetic skills should be proficiency-based vs. the traditional time-based model. Finally, VR was used in subjects with Parkinson's disease in an attempt to improve their gait performance. In this test, the VRLE provided visual, aural, and haptic feedback to enhance motor learning through problem-solving. While walking on a treadmill, the subjects had to navigate obstacles in the virtual environment along two planes.[48] Subjects demonstrated significant kinesthetic (17.4%) and cognitive (31%) improvement gains in the VR environment over the treadmill alone. Additionally, they improved in tasks related to the ones tested, but not specifically trained for.[49] The discussed studies demonstrate that affective, cognitive, and kinesthetic learning can occur when using VRLEs. However, feedback is important to the subject, specifically tactile and haptic. Next, the important design characteristics of VRLEs will be discussed.

Fowler in his article *Virtual reality and learning; where is the pedagogy*, states that VRLEs need to create new learning experiences, not just emulate old ones. Otherwise, the VRLE is nothing more than a nice virtual classroom.[50] Fowler's three defining characteristics of VRLEs, taken from Dalgarno and Lee, 2010, are the illusion of three dimensions, smooth temporal and physical changes, and a high level of interactivity. The representational fidelity and learner interaction combine to create a psychological experience described as a sense of being there or sense of presence or even a sense of being there together (for groups).[51] This presence is vital to bridging the technological, psychological, and pedagogical experiences that occur in learning. Fowler's framework for curriculum in the VRLE starts with the introduction and explanation of a new concept to be learned. It is followed by an opportunity for the student to explore, manipulate, and ask questions reinforcing the need for collaboration in the educational or training structure. Interactivity defines this step and feedback as pivotal. This is easily done in a real environment. Finally, the student needs to test their understanding of the new concept through interaction and experimentation.[52] This curriculum provides a framework for presenting material to elicit immersive, deep learning, but it does not speak necessarily to a student's motivation. Psotka advocates for greater gamification in VRLEs because games challenge students and create local goals which intrinsically motivate the player.[53] Digitally native students today are highly engaged and familiar with a range of complex technologies. New technologies offer opportunities to engage students and drive self-directed learning in exciting ways. In this way, VRLEs are a disruptive technology because they create educational environments that run contrary to the traditional industrial model. By making VRLEs like the games students play and creating experiences that closely mirror how they technologically interact with each other in their daily lives, we can radically change teaching and learning opportunities.[54] VRLEs are not simply the new trendy toy; when they are created to provide guidance, and based on sound educational principles, they can create extraordinary learning experiences within an empowering structure. Creating VRLEs focused on student-centered exploratory learning can guide the student through Kolb's experiential learning cycle while motivating them to engage the curriculum, resulting in a more immersive learning experience and a deeper level of learning.

Learning style preferences provide a key insight into how a student learns, but many other factors play a role in the learning process. These factors include the student's interest, level of mastery, their active participation in the learning process, the affective domain of the student, and their motivation. A student's motivation can be both intrinsic and extrinsic with the greater learning occurring when the student is intrinsically motivated to learn the material.[55] Affective, cognitive, and kinesthetic learning can occur in VRLEs assuming the environment is multimodal with good visual fidelity. It also must provide appropriate tactile and haptic feedback. These factors in addition to the effect of learning styles in the VR environment were considered during the development of the TLST.

Targeted Learning System Theory

The Targeted Learning System Theory (TLST) is a performance-based educational and training structure grounded in student-centered experiential learning aimed at maximizing human potential. The TLST is a combination of art and science that uses technology to create an intelligent system capable of providing adaptive curriculum across an array of training or educational requirements. The art of the TLST consists of creating a proper structure that empowers the students, encourages collaboration, and allows students to take ownership of their learning. The science of the TLST fuses multiple technologies to create real-time feedback loops and adaptive curriculum that adjusts to maximize their learning across multiple learning pathways.

The TLST is designed to make better use of time and information than traditional models by giving students the structure and the tools to be self-maximizing learners without changing the current standards or requirements. The TLST uses immersive experiences, gamification, and minimal guidance to create multiple learning pathways within an experience. In theory, the immersive learning experience can be real, simulated, or virtual but for the TLST to be effective, it must be possible to measure the person, the environment, and their performance. Using immersive exploratory environments produces a cycle of trial and error, creating conscious and subconscious cognations that students believe are real. The student's biological factors, cognations, decisions, and behaviors are then measured as performance and assessed by the system to create improvement feedback loops. Learning begins as the student attempts to make sense of the world around them to consciously or subconsciously understand the underlying principles and dynamic relationships within the context of the situation required to achieve success.

To maximize the benefits of the TLST, the educational structure guiding the learning experience must be a collaborative student-centered performance-based environment. It must provide the student with tools to help them understand how they learn best while providing psychological safety to encourage exploration and sharing. To engineer this structure, educators must focus on creating self-awareness, and evoke curiosity, and passion within the students. Educators or instructors must help students connect their internal beliefs with the learning experience. Students must feel valued, know why they are doing what they are doing, and understand the importance of what they are doing. The collaborative environment surrounding the TLST should make maximum use of knowledge linkages that provide a learning experience equal to the sum of all the parts, not an experience minimized by silos of specific subjects. It should help students learn from their experience through formal and informal discussions with instructors, peers, and personal reflection. There are many ways to create empowering and collaborative educational structures. How an educator or instructor designs a learning environment and sets a strategic culture aimed at creating self-actualization is the art.

There is never one right answer on how to create an empowering structure. It will often require constant adjustment by the educator to adapt to their target audience, changes in curriculum requirements, and technology available. Any changes, however, must be rooted in what is best for the student and their learning. The above synopsis is a wave top discussion of the art required to effectively leverage the scientific technologies utilized in the TLST. The goal of the structure is to get students to a self-actualized point with a solid foundation of self-awareness, motivation, and purpose. Most of this study focuses on the engineered or science portion of the TLST, but it should be noted that the more empowering, collaborative, and self-actualizing structure an educator can create, the more benefit they will get from a TLST setting.

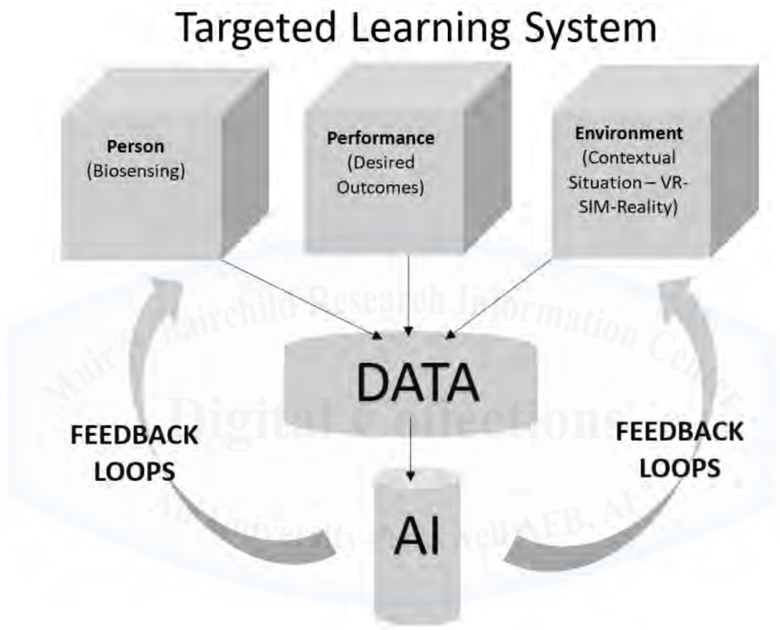

Figure 4. Targeted Learning System Theory visual model

The scientific portion of the TLST involves fusing technology to create learning tools for students while measuring the person, environment, and their performance to build datasets for student and system feedback. Capturing these datasets allows the system to provide adaptive curriculum to the individual student based on their performance level. By adaptively increasing or decreasing the difficulty of the learning environment the system creates customized iterative learning for the student. The system can also manipulate the environment to inject surprise, uncertainty, or complexity into a situation. Additionally, the collection of data can provide insights for the institution, for training selection, remediation, or performance advancement by using performance indicators indicative of success, failure, or re-train. A key component of the TLST is to have each data stream captured simultaneously so that at any given moment of a training session the instructor can correlate a student's performance, their relationship to the contextual environment, and how they are being affected biologically and neurologically. Each part of the TLST will be further broken down below.

To measure the person, also called biosensing, the TLST uses noninvasive integrated technologies. Biosensing could be any biological factor that could play a determinate factor in the performance outcome. In the purest form of the TLST, we would measure every biological factor available about a human such as sleep, intestinal bacteria, hydration levels, vitamin and hormone levels, cognitive load, eye-tracking, heart-rate, respiration, etc. The bio-data influences the student's curriculum real-time by providing feedback on how their current biological and neurological state is affecting their performance at a given task. For example, eye-tracking measurements inform where in the environment a subject is looking. If the task is driving a car at a given speed and eye-tracking indicates the student is not meeting performance standards because they are not looking at the speedometer frequently enough, this would be useful feedback. How often is frequently enough? This is where what right looks like comes in. When data on a task has been captured across multiple students, the system would be able to provide initial guidance to the student like "the best drivers look at their speedometer every 2 seconds." This would be a starting point until enough data on a student is collected to determine how often they as an individual should look at the speedometer to maximize their performance. For an organization, all these datasets could provide clues as to what biomarkers might indicate the best skillsets suited to a given task so predictive analytics could be used to help find the right people for the right task.

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Performance is measured by creating datasets linked to desired outcomes for the training and education that is occurring. In the above example, the performance was the ability to maintain a certain speed while driving within parameters of the speed limit. These parameters would be set by the educator based on the level of performance desired for the task or content. Higher performance usually has less degree of tolerance for error. While we advocate for exploratory learning, some measure is required to validate that learning has occurred. The performance measurement along with bio-indicators confirms that the student is ready for more complex tasks, indicates they should regress, or just should spend more time at the current level.

The environment is any contextual situation that formulates the learning experience in a VRLE, mixed reality or physical environment. In theory, capturing this dataset involves measuring every variable available in the environment. Since not every variable can be measured, it requires someone to prioritize the variables that should be measured depending on their impact to the learning experience. In digital environments, these are easily captured, but in simulations and physical environments, it becomes exponentially more challenging. This dataset is valuable because the conditions within an environment affect performance and the person. Back to the car example. When the student is asked to perform the same task in a thunderstorm, it becomes more difficult. They would likely focus more outside the car to ensure they stay in their lane, and the difference in road conditions may raise their anxiety level making them want to drive slower and failing to meet the performance requirement. On the other hand, when they have mastered performance requirements on a clear day and are starting to become complacent with the task as indicated by their biosensing measurements, the system could change the environment and continue to challenge the student with more complex tasks and content. Anyone of these datasets alone could provide a wealth of information for the student and educator, but

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when fused together they create a holistic picture of where the student is in their learning and ways the educator can help the student move forward faster.

The adaptive curriculum described above is driven by feeding these data streams into an Artificial Intelligence (AI) neural network. The AI will sort and prioritize all these variables to create feedback for the student and modify the environment to progress the student along in the curriculum. Greater deviation rates from a given performance standard would elicit greater guidance and cues from the AI and would reduce assistance as student performance improved. The student's progress is recorded along with a performance report that is visualized for personal reflection, and for a follow-on face to face debrief with an instructor or teacher. The progress and performance reports are distilled from both formative and summative assessments that occur during the interaction with the system. By digitizing people strengths, weakness, characteristics, and performance the TLST also allows for datasets among multiple students to be compared for personnel management placement and selection.

The student-centered portion of the TLST provides students with multiple learning pathways within an experiential performance-based structure and the option to iterate as necessary. Part of the multiple pathways included are capitalizing on multiple modalities as described in the VARK - visual, auditory, read/write, and kinesthetic. [56] The other part of the pathways implements the experiential learning cycle as described by Kolb - a loop of concrete experiences, observations, and reflections, forming abstract concepts and generalizations, and testing these concepts in new situations. [57] These technologies allow the student to have a student-centered learning experience empowered by choice driven by high-fidelity performance data. Additionally, by allowing the AI to guide student learning based on the student's performance, it allows one educator to supervise multiple students. It also allows an organization to implement a performance-based model instead of the traditional time-based industrial model. The performance standard and time spent achieving that standard is variable depending on the complexity of the task and risk aversion of the organization. Why should a student who can learn to drive the car in five hours be forced to sit through 20 hours of driver's education?

In this study, the TLST was used to develop a mixed reality teaching tool called the Adaptive Flight Trainer (AFT) that was optimized to flight training. Although the TLST was applied to flight training for this study, the TLST could apply to many other educational and training opportunities if the technology was customized to produce the necessary datasets for the required education or training outcomes. The TLST maximizes learning and elevates performance through empowerment and technological leverage. The student empowerment provides the energy for iterative exploration of immersive learning environments, and the technological fusion enables customized feedback loops and adaptive curriculum that synthesizes the accumulation of knowledge and skills. Looking towards the current pilot shortage within the USAF and the creation of Pilot Training Next, the AFT was used to test concepts of the TLST and the impact it could have on flight training.

The Adaptive Flight Trainer

The AFT was developed to demonstrate the applicability of the TLST to a current USAF problem. As previously discussed the USAF is experiencing a pilot manning crisis, extenuated by the limitation of expansion in the production pipeline. The use of emerging technologies to increase production is being explored by Pilot Training Next, and this research provided the baseline for their initial virtual reality trainers. The focus when designing the AFT was to incorporate commercial off the shelf (COTS) technology to help reduce costs, find initial integration and capability problems to inform Pilot Training Next and demonstrate the feasibility of scaling the system. Additionally, it tested leading research theories on learning in the VRLE through the lens of flight training.

Hardware

From a hardware perspective, all the technology could be integrated by an average video game enthusiast. In fact, three prototypes to include the assembly of three gaming chairs was accomplished by the research team in approximately 3 hours. The prototype ran on a Predator Laptop by Acer with an Intel Core i7, GTX 1060 graphics card and basic windows 10. The VR headset selected was the HTC VIVE because of our industry partners' familiarity and the inherent eye tracking capability it provides, although we believe another headset, for example, the Oculus Rift, would have been acceptable as well. The gaming chair selected was a racing style chair whose unique characteristic was the ability to attach side and front platforms to mount the control stick and rudder. The control stick and rudder were from the Thrustmaster Warthog Series, selected because of their plug and play capabilities with the software, numerous switch options, and sturdier feel than the typical plastic gaming controls.

The only hardware that was modified was the VR headset. First, Pupil Lab cameras were installed around the two interior eyepieces to visually record the eye to the fidelity needed by the lead contractor, Senseye Inc., to measure the wearer's cognitive load. This camera was selected because of the picture it captured, but also because it is easy to install (snaps in) and provides a noninvasive way to capture the eye images. It consists of a small camera and several infrared lights that illuminate the pupil and record the wearer's eyes. In fact, when wearing it, subjects did not even notice the camera, and it does not impede the field of vision. Additionally, adding a Leap Motion camera to the front of the headset enabled the wearer to interact with the virtual environment with their hands. The Leap Motion camera captures the physical image of the

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wearer's hand and creates an avatar of the hand in the virtual environment. The avatar hand can then interact with the control stick, throttle, and cockpit switches in the virtual environment with no actual tactile interaction. In all aspects of the hardware commercial availability and costs were considered, and except for the Pupil Labs camera, everything was purchased from Amazon. The total estimated cost for all hardware required to build one prototype is six thousand dollars.

Figure 5. Enlisted subjects in the Adaptive Flight Trainer

Software

The primary software utilized for flight simulation was Prepar3d v4 (pronounced prepared), a Lockheed Martin product that is commercially available. It is a fully VR compatible environment that gives the user control over almost any imaginable variable from weather to aircraft malfunctions. An initial limitation with Prepar3d was the lack of a T-6A Texan II model in the environment. This was overcome through our partners at Pilot Training Next reaching out to Lockheed, Raytheon, and a private developer to acquire rights to have the model added to the environment. A further issue with the updated model was poor visual fidelity of the airspeed indicator and altimeter, it was difficult to read the numbers associated with the indicators' needles. Adding a small digital overlay display to the bottom of each instrument, allowed the airspeed and altitude to be displayed with appropriate contrast.

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In addition to modifying the T-6A model, VRLE learning theories were incorporated into the Prepar3d virtual environment. Using a developer license, industry partners programed three learning scenarios within Prepar3d to incorporate multimodal learning cues, and data capture scripts. The targeted data included aircraft airspeed, aircraft altitude, aircraft position, subject eye movement, and subject cognitive load parameters throughout the entire scenario. The scenarios incorporated aspects of the developed construct validity for a VRLE and various elements of multimodal learning theories. Particularly they provide cues that reduce the cognitive workload typically required for a subject to orient themselves in the virtual environment. The cues were multimodal in that they instructed the subject visually and aurally. The scenarios incorporated elements of gamification and exploratory learning to engage the subject and were sufficiently short to allow for multiple iterations. Since subjects would receive no instruction from the observers the goal of the environment was to create an opportunity for the student to learn and practice the task on their own, while providing cues to enable a focused, faster and deeper learning than a traditional "free play" environment.

Adaptive Virtual Reality Learning Environment

The first scenario provided bright green gates to form an outside box pattern with arrows to help guide the subject through 90-degree turns. The center of each gate was set at the required altitude and extended 100' above and below. The inside "closed" pattern was comprised of red boxes to differentiate the ground track the students would follow (Figure 6). In the final stages of the pattern the red boxes "descended" down to the runway on a standard three-degree glide path to guide the student to land on the runway. The scenario provided corrective instruction through aural cues when the subject deviated from a flight standard. If they were 100' or greater off altitude, they would hear "Maintain 1200 feet". If they were 10 knots or greater off airspeed, they would hear “Maintain 200 Knots”. If they failed to retract or extend the landing gear or flaps, they would hear “Landing Gear” or “Flaps”. The second scenario still had gates, but they were visually depicted using thin yellow lines, making them more difficult to see (Figure 7). The third scenario the gates were made invisible, and no aural corrective cues were provided. To provide feedback to the student, a post sortie Debrief Tool was built to graphically depict the student’s position, airspeed, altitude, and cognitive load (Figure 8). All measurements were relative to the assigned standard except for their cognitive load because it is unique to each person.

Figure 6. Virtual Learning Environment Level 1

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Figure 7. Virtual Learning Environment Level 2

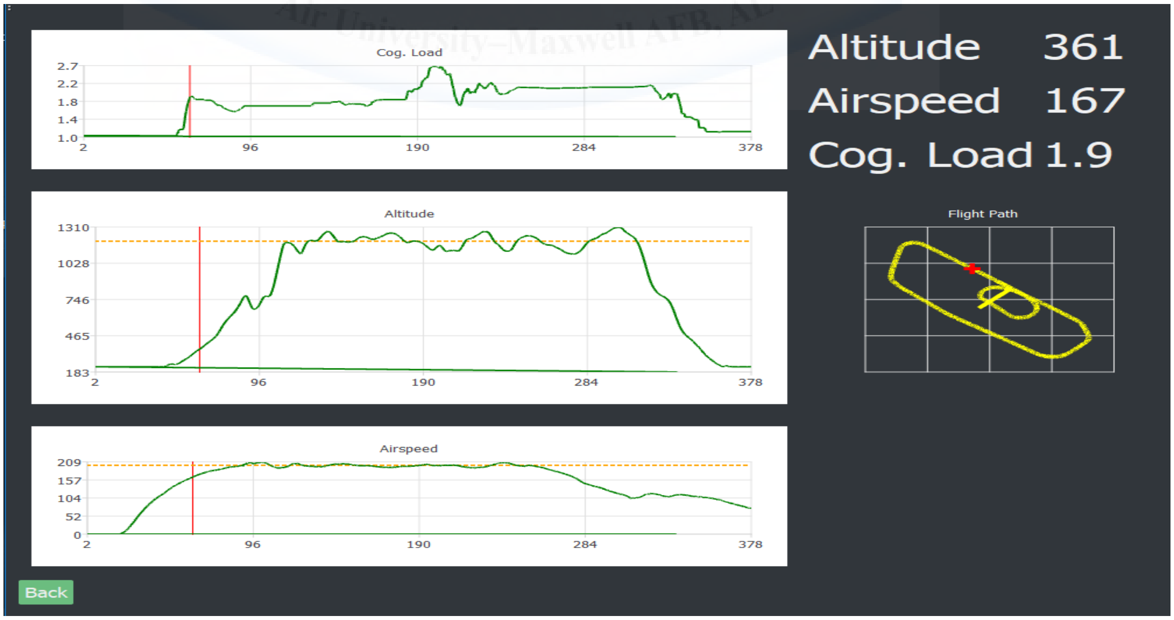
Altitude 361
Airspeed 167
Cog. Load 1.9

Figure 8. Post Sortie Debrief Tool

Artificial Intelligence

The AFT and VRLE did provide real-time feedback to the student through visual (gates) and auditory cues, but it did not have the AI engine incorporated that would manipulate the student’s experience to maximize their learning. Theoretically, the AFT as described above would utilize a real-time AI engine to manipulate the VRLE to maximize student learning as indicated by their biological measurements. A system of this type would be known as an intelligent tutor. Unfortunately, the real-time AI feedback loops in the AFT could not be incorporated due to financial constraints and time limitations. To begin development on the scale envisioned for this project would have cost over $50,000 which would have taken too much of the project budget. Additionally, more time is required to train the AI model what right looked like, and it would have required a substantially more powerful computer. However, the information collected from interviews with commercial AI companies indicate that using real-time AI for flight training and other learning opportunities is well within the realm of possible. The need to test the AFT before February 2018 to support Pilot Training Next limited the ability to pursue a fully trained AI. However, the multimodal VRLE scenarios levels 1-3 and Debrief Tool provided the necessary feedback to students to enable an initial test of the TLST concepts in a reasonable budget and time while validating the concept that an adaptive performance-based system is possible and productive. Following the AFT test, a machine learning algorithm was created and used to analyze the data collected and will be covered in more detail in later sections. Although the algorithm did not directly contribute to student learning during the AFT test, it will help provide a foundation of predictive measures that can be incorporated into future studies that will further the development of real-time adaptive curriculum.

Methods, Assumptions, and Procedures

Methods

The primary goal of the AFT test was to measure the cognitive and kinesthetic transference, or learning, from a VR trained task in the physical environment. A secondary goal was to identify affective feelings towards the VR environment when utilized in a flight training construct. The tertiary goal was to identify post-test what if any, determinant variables and neurological activity could be identified that might indicate a higher propensity for an individual's success in flight training. Finally, the test looked to inform the Pilot Training Next team by testing the AFT technologies, virtual environment, and providing the team with initial trend data regarding the effectiveness of the AFT in teaching flying skills. This data was collected utilizing multiple assessments as well as performance, cognitive load, and eye-tracking data from the virtual and physical environments.

Cognitive transference was measured using a series of procedural tasks that subjects had to complete during their task, specifically five radio calls and a requirement to raise and lower the landing gear and flaps within a certain airspeed limit. Kinesthetic transference was measured based on the subjects' ability to physically fly the aircraft and execute an effective cross-check to maintain an assigned airspeed and altitude during the task. Affective assessments using a Likert Scale were utilized to gauge subjects' comfort level with VR and their perceived applicability of the environment to flight training. This test was covered under an Institutional Review Board (IRB) exemption given by the Air Force Research Lab at Wright Patterson AFB, OH.

A baseline measurement was taken with the subjects executing the assigned task in a T-6A Texan II Operational Flight Trainer (OFT). The OFT is a physical simulator used by all UPT students throughout their T-6A training. The same day following the baseline measurement subjects were each given a 30-minute student-centered VR training session on the task in an AFT. The following day subjects were given an opportunity to train for up to one hour in the AFT. The final evaluation of the task was completed in the OFT utilizing the same procedures and taking the same measurements as the baseline assessment. The only data evaluated to indicate performance improvement was data obtained during task execution for each subject in the OFT. Data collected in the AFT was used to identify trends in performance and test subjects' learning in the virtual environment.

Test Procedures

Participants

All subjects for this test were permanent party volunteers from Columbus AFB. The test group was a convenience sample comprised of USAF active duty, reserve members, and DOD civilians. The test subjects were originally divided into three groups: a non-tactile group (Longhorn), a tactile group (Hokie), and a control group (Aggie). One of the original variables to test was the importance of tactile inputs to learning in a VRLE. Utilizing Leap Motion technology, the Longhorn group would fly using a virtual control stick and throttle as opposed to a physical stick and throttle that integrated with the VRLE (i.e., when moving the physical controls the virtual controls moved as well). However, during execution, the technology did not meet expectations. It was discovered that when a subject looked away from where their hand was to look outside the aircraft, their avatar hand would disappear, and the subject would no longer be able to utilize the virtual controls. After attempts to mitigate it was determined that no useful training could occur because the subjects needed to be able to look outside the aircraft to execute the task. The non-tactile group was switched to tactile training to increase the pool of subjects for the other test variables.

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The Longhorn and Hokie groups were comprised of 15 people each, further divided into three subgroups based on flight experience, no member of these groups had any experience flying the T-6A. The first subgroup (01-05) consisted of nine males and one female, all experienced pilots. The average age for this subgroup was 37.8 years with an average of over 2600 flight hours. The second subgroup (06-10) consisted of eight males and two females, with limited flight experience. The average age for this subgroup was 23.9 years with an average of 17.7 flight hours. The third subgroup (11-15) consisted of nine males and one female with an average age of 23.2 years and had zero flight experience. The Aggie group was comprised of nine males and one female who were current USAF Undergraduate Pilot Training students. The average age for this group was 24.1 years, and they averaged 55.7 hours of flight experience with an average of 17.8 hours of that time being in the T-6A Texan II. All subjects of this group had either recently completed their pattern only solo flight or were about to solo. The logic of using them for the control group was that they would be the most proficient students available at the task the subjects would perform. Instructor pilots would likely have flown a better control profile, but the ability to compare the performance of a student who was completing a traditional training program versus the VRLE added more value.

The final group of participants was the observers. This was a group of volunteer instructor pilots who assisted in running the AFTs, the OFT, escorting subjects to and from events, and collecting procedural data for each sortie. Before the start of the test, the researchers met with the observers to teach them how to operate the AFT, standardize actions, and coordinate a standardized data collection and storage process.

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Task - One Visual Flight Rules Overhead Pattern

The subjects were evaluated and trained on the USAF visual box pattern to an overhead break flown at all UPT bases with some slight modifications. Additional radio calls were added to increase the number of procedural data points that could be measured. The only complete reference the subjects had was a visual depiction of the task given to them during their evaluation and training sessions (Attachment 1). The task was selected because it requires multiple skill sets to accomplish and is one of the first things required to be mastered by USAF pilots. To accomplish the task subjects must effectively monitor their airspeed and altitude within the aircraft while continually referencing their lateral position outside the aircraft. Each iteration of the task challenged the subjects with a takeoff and landing as well as multiple airspeed, altitude, and lateral position changes.

Execution Timeline

The test occurred at Columbus AFB from 9-12 January 2018. The test started late afternoon 9 January with an orientation for all the subjects and observers. The orientation covered the researchers' backgrounds, the purpose of the study, what data would be collected, and answered any questions the subjects had. Additionally, 15 subjects were identified by the AFRL researcher to wear a Zephyr Band that would collect heart and respiration rates during the events. Before leaving the orientation, all subjects received their callsigns, schedule of events (Attachment 2), and completed a VARK assessment and the Learning Styles Inventory version 3.1 (Attachment 3). Permission to utilize these assessment tools for the research was obtained from both parent companies.

The baseline assessment was conducted on 10 January utilizing a classroom space and an OFT simulator provided by the 14th Operations Group. Subjects arrived in the classroom 30 minutes before their scheduled OFT flight (box time). Upon arrival, subjects were instructed to complete a Pre-Test Assessment (Attachment 4). If the subject was selected to wear a Zephyr Band, it was put on by the AFRL researcher at this time. Due to the tight schedule observers were instructed to escort the subject to the OFT five minutes before the scheduled “box” time. Fifteen minutes before OFT baseline measurement the subjects were given their task instructions (Attachment 5) and their task card (Attachment 1). Subjects were given ten minutes to study the task instruction and card. They were not allowed to ask any questions, and no additional instruction was provided. At the end of the ten minutes, the task instruction card was returned to the observer, and the subject was escorted to the OFT.

Before the subject’s arrival at the OFT the observer reset the simulation and properly configured the aircraft with engines running on runway 31L at Columbus AFB. The subject was then helped into the OFT cockpit but was provided no instructions by the observer. The observer placed the glasses with a camera on the subject. The camera was used to record the subjects eye during the task for later cognitive load measurements. Once the camera was in place, the observer verified proper alignment and asked the subject to close their eyes and take ten deep breaths. This was to relax the subject so that a baseline cognitive load measurement could be established. While the subject’s eyes were closed, the observer started recording. The task started when the OFT operator cleared the subject for takeoff. The OFT operator recorded procedural data utilizing a Manual Task Tracker spreadsheet (Attachment 6), but other than giving the required responses to the subject’s radio calls, provided no instruction. Subject flight performance was recorded utilizing a Go Pro camera that recorded a screen with the cockpit instruments displayed. Upon completion of the OFT flight, the subject was escorted back to the classroom and released until their scheduled AFT training time.

Three AFT prototypes were set up in the 41st Flying Training Squadron to conduct the VR training sessions. The original test plan scheduled each subject for two one-hour sessions of VR training before the final OFT evaluation. Despite multiple tests on the equipment the day prior technical trouble with all three of the AFT prototypes put the VR training sessions three hours behind schedule. As a result, the VR training sessions on the first day were shortened to 30 minutes, and the second-day sessions were left at one-hour. Subjects arrived approximately 10 minutes before their scheduled training time (15 minutes if they were selected to wear a Zephyr band). Upon arrival, subjects were given their task instruction (Attachment 5) and their task card (Attachment 1). Unlike the baseline OFT sortie, the subjects could keep the task card to reference for the entirety of their VR training sortie. The task card and instructions were returned at the end of each training session. Once the headset was placed on the subject's head, it was calibrated to their eye using a custom written script to ensure quality eye data was captured. The subject would then close their eyes before each sortie and take ten deep breaths to relax the so that a baseline cognitive load measurement could be established. All subjects started in scenario one, developed to provide the most guidance and instruction to the student. The scenario started when the observer cleared the subject for takeoff. The scenario would last until the subject crashed, landed, or asked to end it. Upon completion of the scenario, the subject would lift their VR headset up and view the Debrief Tool (Attachment 7). No instruction on the use of the tool would be given. The observer would provide radio call and configuration feedback based on the subject's performance verbatim from the script provided (Attachment 5). The subject was then asked if they would like to remain at their current scenario level or move to a different scenario. The training sessions were set up to be student-centered, so they controlled which level they trained with for each sortie. At the end of the final VR training sessions, the subjects completed a Post-Training assessment (Attachment 4) and were released until their final OFT evaluation.

The final evaluation was run identical to the baseline OFT evaluation. Upon completion of the study, the subjects filled out a Post-Test Feedback to provide insights for Pilot Training Next on the perceived effectiveness of using VR to conduct aspects of pilot training.

Limitations

One limitation of the study was the amount of training time available and the number of participants. Because the test used USAF resources that were also required to execute an on-going pilot training mission we were limited in how much time we could have the subjects and OFT simulator. Additionally, while ACSC was accommodating with some time off, we could not realistically miss the amount of time necessary to run this study with multiple iterations of large subject pools. This test alone required 12 hours of OFT simulator time and 45 hours of AFT training time. We also recognize that our subjects were a convenience sample and would have preferred a more robust randomized subject pool. However, it was not possible with the time and resources allotted.

On the technology side, the limitations LEAP Motion for the task’s non-tactile purpose was discussed earlier. Additionally, there were data storage limitations as a result of running each AFT prototype using a laptop. In total over 600 GBs of data were collected from this study. The decision to use the laptops was made to increase mobility, however as data was collected, it slowed down the laptops, causing a lag increase in the VRLE. A workaround was to regularly download the data onto flash drives, but for long-term implementation, this would be a limitation of the current prototype design. A further limitation was the inability to capture each data stream concurrently with timestamps to overlay activities with data. Also, digital data was unable to be

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collected from the OFT. A partnership with the AFRL Continuous Learning and Assessments Branch to record the digital data directly during the OFT sorties did not work out due to contracts and the permissions to access proprietary aspects of the simulators not being given. To collect the data, a Go Pro was set up in the OFT recording the instruments at the observer's station. This provided video of each subject's performance but did not provide the ground track. To assess the data a program using Mathematica software was written to visually identify the subject's airspeed and altitude based on the position of the indicator's needles and record that data for analyzation.

Additionally, some human factors limitations that were not expected occurred, mostly as a result of providing no instruction other than the task card. The first was using non-standard switches for landing gear and flap actuation. While subjects learned the concept of raising and lowering the landing gear and flaps when they transitioned out of the VRLE some did not make the connection between the switch positions in the VRLE and where those switches are located in the real cockpit. Another factor was the "fly through" boxes in the VRLE. Some experienced subjects initially dodged the boxes like they would any other obstacle in the air. The inner "closed" pattern "fly through" boxes were purposefully designed in the VRLE to be a different color than the outer "box" pattern "fly through" boxes. The reason was to differentiate between the two separate ground tracks of the pattern to avoid any potential confusion. However, in module one the outer pattern boxes were green, and the inner pattern was red. This led to more confusion because some subjects thought that after flying through green boxes, flying through red boxes would now be bad. In this case, if a subject asked if the red boxes were bad, they were instructed that they were okay to fly through. This highlights the importance of operator and engineer coordination during design phases to ensure human factors are considered.

When developing the AFT, it was understood that the lack of haptic feedback could be a limitation, but it could not be incorporated because the cost was outside the available budget. The T-6A stick has a pivot point in the floor approximately 15.5 inches below where the pilot is sitting. An attempt was made to replicate the stick throw but integrating the COTS technology was too great a challenge in the time available. As a result, the stick pivot point in the AFT was approximately six inches above where the subject was sitting. Additionally, when the subject pulled back on the stick, there was minimal resistance. In the T-6A OFT, a significant amount of force is required to pull the stick back and hold it in position for level flight. Since an acceptable solution could not be found in time, it was noted to observe for possible negative transference, and the test pressed forward.

The greatest limitation of the study was the virtual T-6A Texan II model. Although visually it looked just like a T-6A, in some regards it did not handle the same. The first challenge was the propeller in the virtual model did not slow the aircraft when the throttle was retarded as it does in the aircraft. This meant that the aircraft did not slow fast enough resulting in most subjects leaving the throttle in Idle from the break until they landed. This does not reflect actual flying technique nor the actual aircraft performance. In the OFT almost every subject lost altitude immediately upon retarding the throttle to idle because they were not used to the sudden decrease in airspeed. Furthermore, every instructor pilot that flew in the AFT pointed out the fact that the rudder forces were not the same as in the aircraft. In propeller aircraft, the P-Factor and torque create rotational forces that require the application of rudder to counter the force and control the aircraft. In the real aircraft, this is a significant learning challenge for most students. In the virtual model, rudder movement was not required to control the aircraft. Like the limitation with the haptic feedback, it was noted for possible negative transference observations.

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Results

Learning Styles

Subjects' learning styles were assessed using the VARK assessment and the Learning Styles Inventory version 3.1. The subjects' self-perceived learning style was assessed with a learning style self-assessment question on the Pre-Test Assessment.

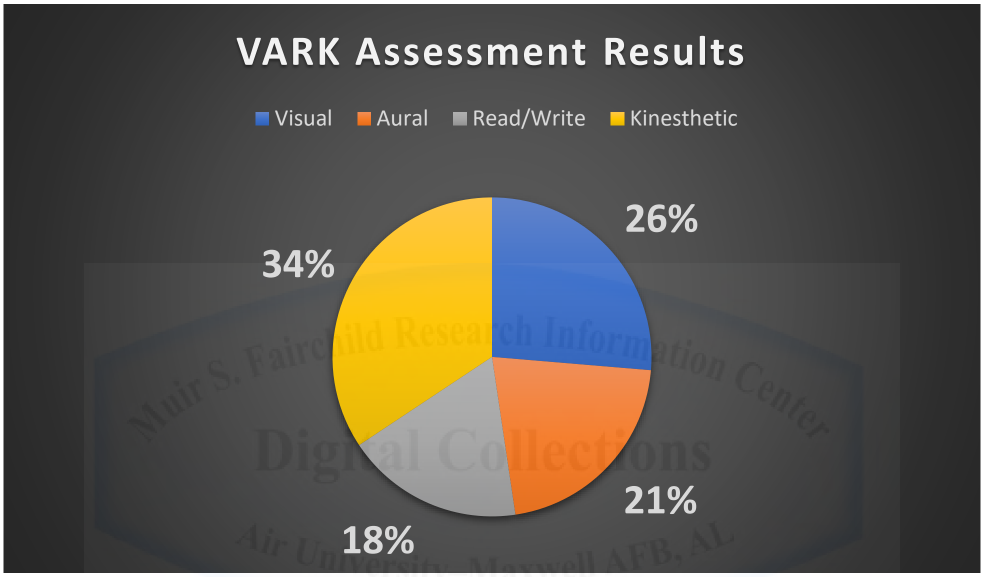

Figure 9. VARK Assessment Results

The VARK assessment did indicate a higher preference of the group towards the kinesthetic learning style however, most participants showed bimodal and trimodal preferences even when kinesthetic was the highest score. On the learning style self-assessment, 70% of the subjects reported kinesthetic as their preferred learning style, however, in the VARK assessment, only 53% scored highest in that style. This indicates that some subjects may not be completely aware of their preferred learning style, and a multimodal learning environment would ensure that all subjects benefit from the instruction.

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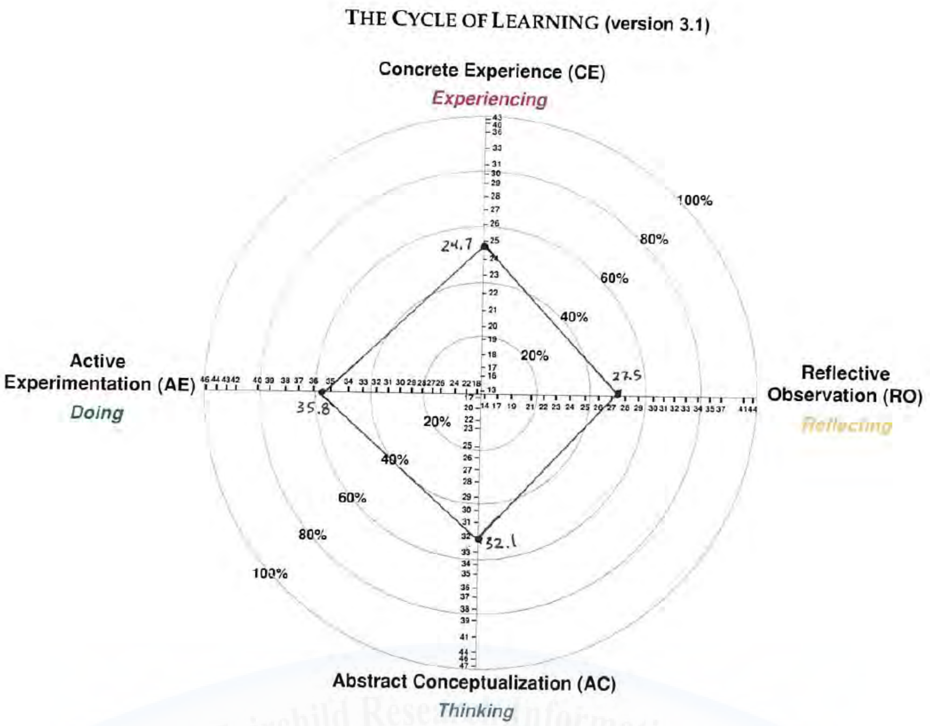

Figure 10. Average LSI results for all study participants

The results of the Learning Styles Inventory showed a slight preference for learning by doing and thinking (the bottom left or converger quadrant). The group averages make it appear that subjects are balanced across all learning styles. However, most individuals were not balanced and favored one or two styles over others. What Figure 10 does indicate is that as a test group there was a wide variety of learners that would each learn differently in the created VRLE.

Affective Results

Subjects' affective learning in the virtual environment was measured utilizing pre and post-training assessments. Likert scores for each of the ten questions were averaged to determine the scores for all study participants as well as each subgroup. Overall subjects indicated affective improvement across all questions except two.

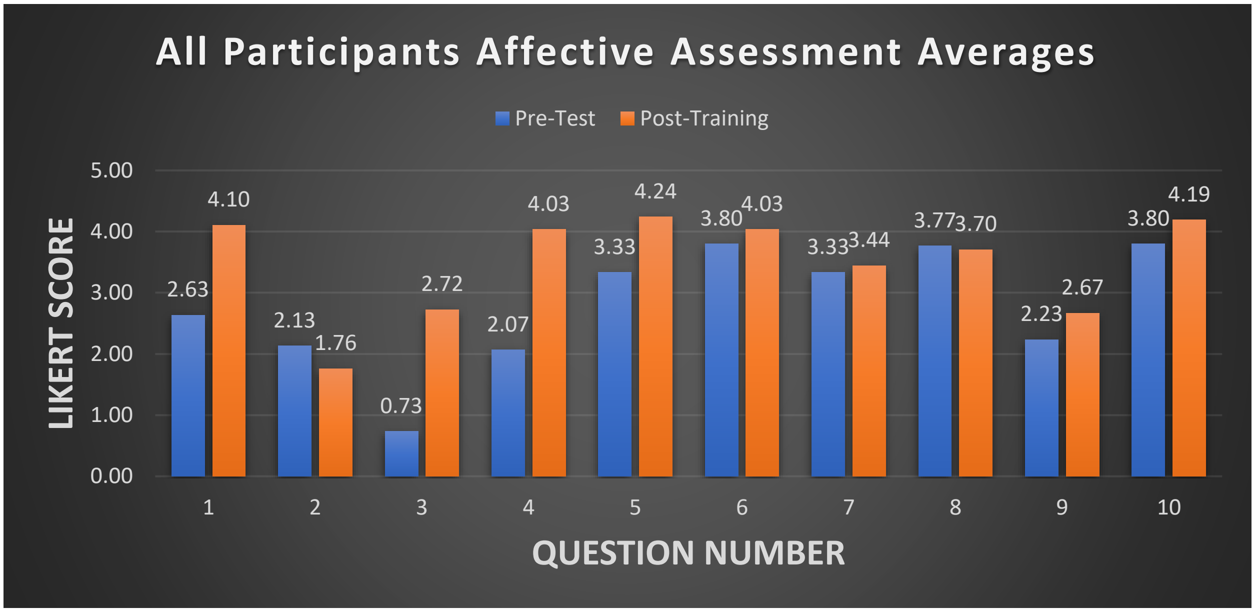

Figure 11. All Participants Affective Assessment Averages

The greatest improvements of 1.99 and 1.96 were observed on questions three and four, relating to the subjects' belief in the knowledge gained in the T-6A Texan II aircraft and the VFR overhead pattern (Figure 12). Additionally, an improvement of 1.47 occurred in question one relating to the subjects' confidence in their ability to complete the required task. The decrease in score for question two shows affective improvement because it gauges the subjects' anxiety level about their upcoming task. Question eight is the only question that decreased, showing a 0.07 drop that does not indicate an improvement. It asked the subjects' belief that the VR environment could effectively simulate the visual act of flying. The control group did not conduct any VR training, therefore, they did not answer any questions about the VR environment. On average improvement across all groups was 0.79.

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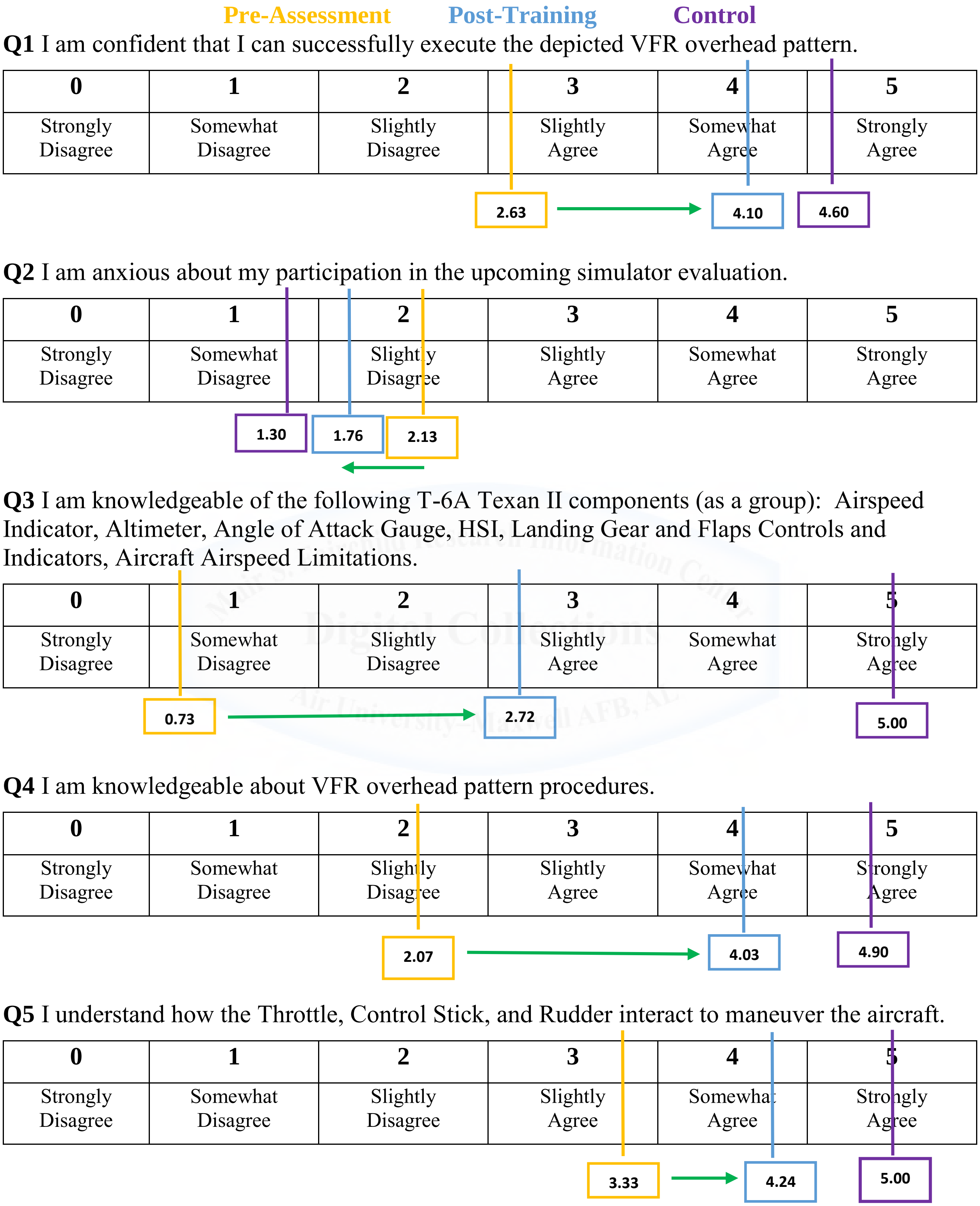
Figure 12. Affective Assessment Average Results with Questions



Q1 I am confident that I can successfully execute the depicted VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Q2 I am anxious about my participation in the upcoming simulator evaluation.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Q3 I am knowledgeable of the following T-6A Texan II components (as a group): Airspeed Indicator, Altimeter, Angle of Attack Gauge, HSI, Landing Gear and Flaps Controls and Indicators, Aircraft Airspeed Limitations.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Q4 I am knowledgeable about VFR overhead pattern procedures.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Q5 I understand how the Throttle, Control Stick, and Rudder interact to maneuver the aircraft.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

`

Q6 I believe that training in the Virtual Reality Adaptive Flight Trainer will improve my performance on the depicted VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

3.80

4.03

→

Q7 I believe the Adaptive Flight Trainer will effectively simulate the physical act of flying (discounting the "seat of your pants" and lack of G-forces).

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

3.33

3.44

→

Q8 I believe the Virtual Reality environment will effectively simulate the visual act of flying a VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

3.77

3.70

←

Q9 I believe the Adaptive Flight Trainer will effectively immerse me in the flight environment to the point that I will forget I am in a simulator (i.e., suspended my disbelief).

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

2.23 2.67

→

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Q10 I believe the Adaptive Flight Trainer could be used to effectively conduct aspects of undergraduate pilot training.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

3.80 **4.19**

→

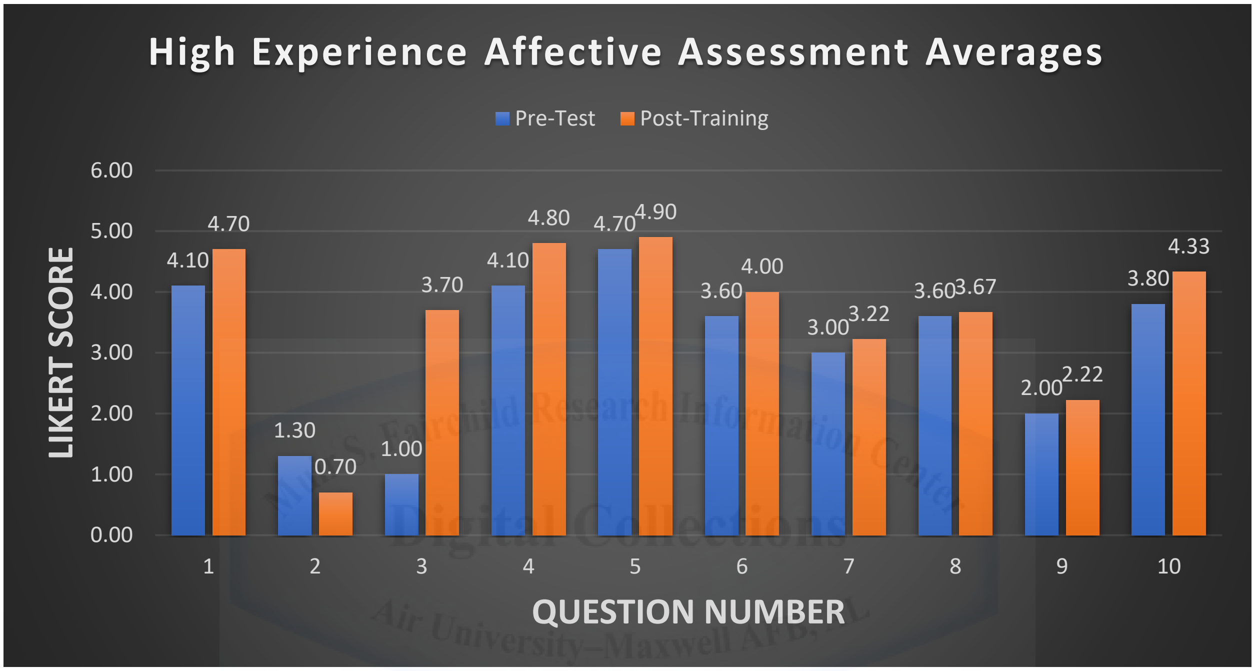

Figure 13. High Experience Affective Assessment Averages

The high experience subgroup demonstrated the highest improvement of 2.7 points on question three referencing their belief in knowledge gained about the T-6A aircraft. This group also demonstrated the highest growth of any group in question ten, 0.53 points, relating to the belief that the AFT could be used to conduct aspects of UPT.

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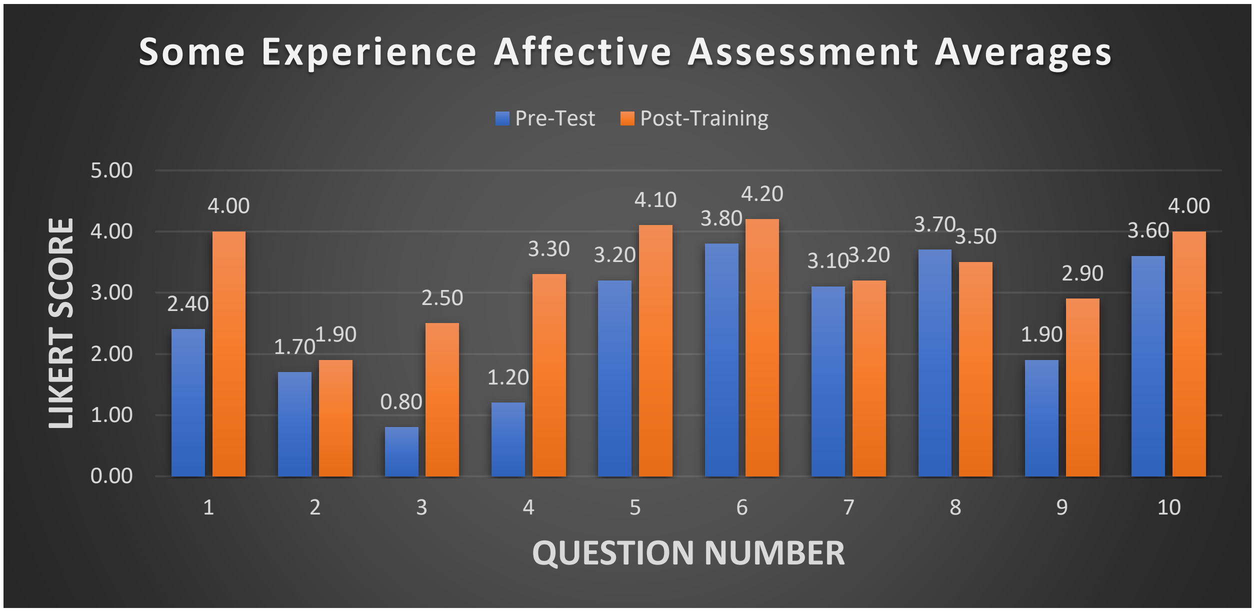

Figure 14. Some Experience Affective Assessment Averages

The some experience subgroup indicated large improvements in confidence (Q1), T-6A knowledge (Q3), and VFR pattern Knowledge (Q4, the largest at 2.1 points). They are the only group reporting a decrease in visual simulation (Q8) and an increase in anxiety about the upcoming task (Q2). This increase might be attributed to the fact that members of this subgroup were waiting to start UPT and psychologically might have attached their performance during this test to their ability to complete UPT. The potential for these psychological attachments was not mitigated by the research team because the possibility was not considered and the connection was not made until after the results of the test were analyzed. This group showed the largest improvement of all the groups (one point) in suspension of disbelief and immersive qualities of the VR environment (Q9).

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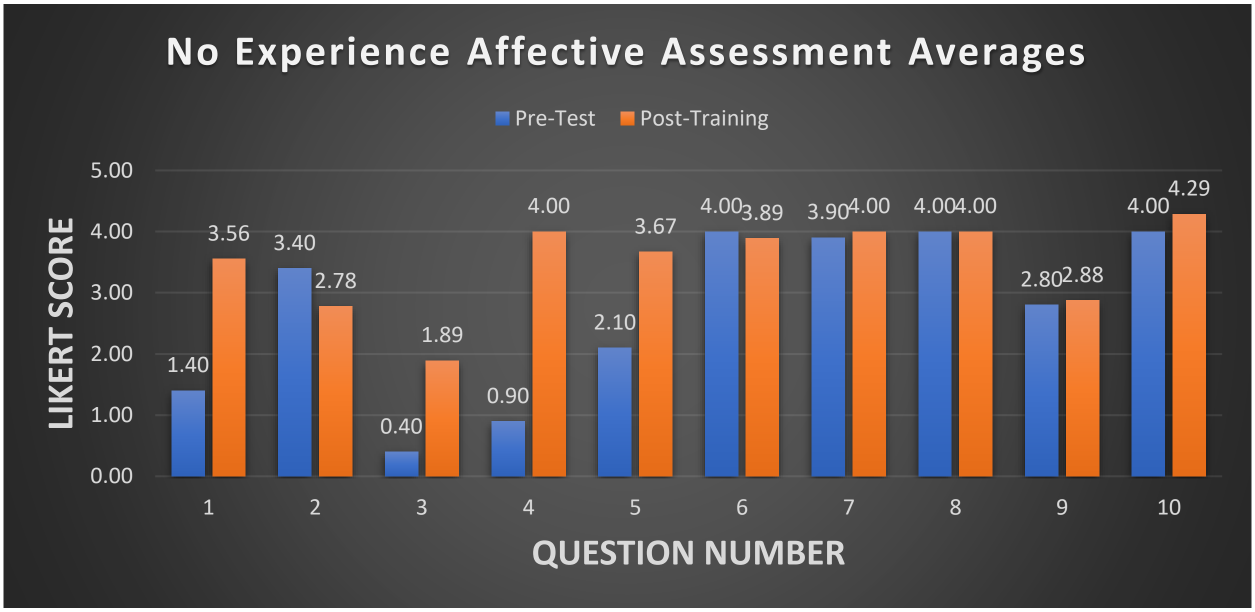

Figure 15. No Experience Affective Assessment Averages

The no experience group showed the largest average improvement across all groups of 0.95 points. The greatest improvement was in the knowledge of VFR patterns (Q3, 3.1 points), confidence in their ability to complete the task (Q1, 2.16 points), and understanding how basic aircraft controls fly the aircraft (Q5, 1.57). They were the only group to demonstrate a decrease in the ability of the virtual environment to improve their performance of the task. (Q6, -0.11). This group also had significantly higher baseline values for questions 6-10, relating to their belief in VR technologies ability to teach and simulate flying the aircraft.

Cognitive Transference Results

Cognitive learning was evaluated using procedural tasks the subjects were expected to learn and accomplish while flying the VFR pattern. They included five radio calls and raising and lowering the landing gear and flaps below the landing gear and flaps airspeed limitation of 150 knots. The cognitive tasks were considered pass/fail and recorded as either completed or not (Attachment 6). For example, if the subject lowered the landing gear above 150 knots, it was considered a failure. Even though they remembered to lower the landing gear, they did not adhere to the airspeed limitation. Additionally, if the radio call was made correctly but not at the right pattern position, it was considered a failure. If the subject crashed before having an opportunity to accomplish the task it was considered a fail. The performance was evaluated using the percentage of procedural tasks the subject got correct for each sortie. During the study, the subject's knowledge of the requirement to a touchdown in the first 1000 feet was evaluated as a cognitive task, however, the results indicated that flight performance and ability were more determinant than cognitive knowledge in whether or not if they could achieve it, so those results are not included in this section.

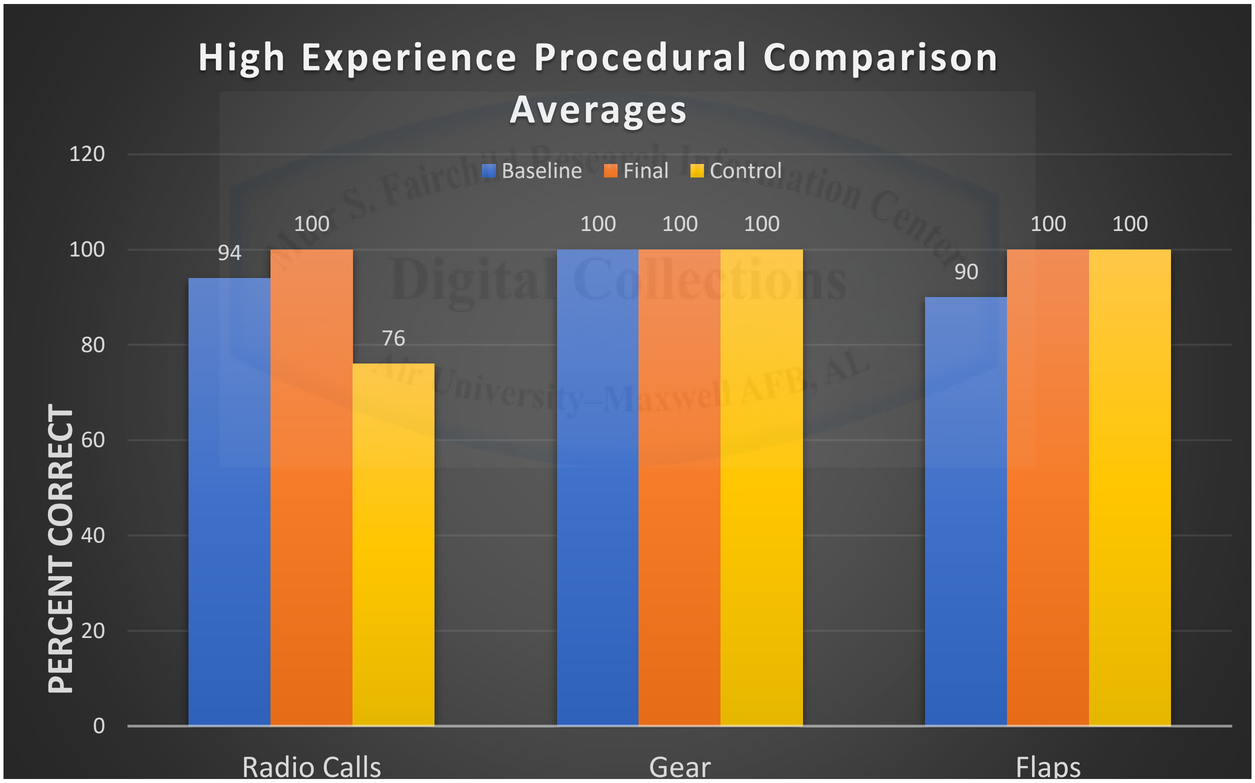

Figure 16. Comparison of High Experience Average Procedural Completion Percentage

The high experience subgroup showed a very high level of baseline performance and improved to a perfect result in the final OFT simulation. This is likely because the procedural tasks, while slightly different for the provided tasks, are inherent to flying any aircraft. This is further illustrated by the control group only making 76 percent of correct radio calls. Two of the assigned radio calls are not typical to the VFR overhead pattern the UPT students fly at Columbus AFB. As such, without training and only looking at the task card for 10 minutes, they reverted to their practiced habit patterns.

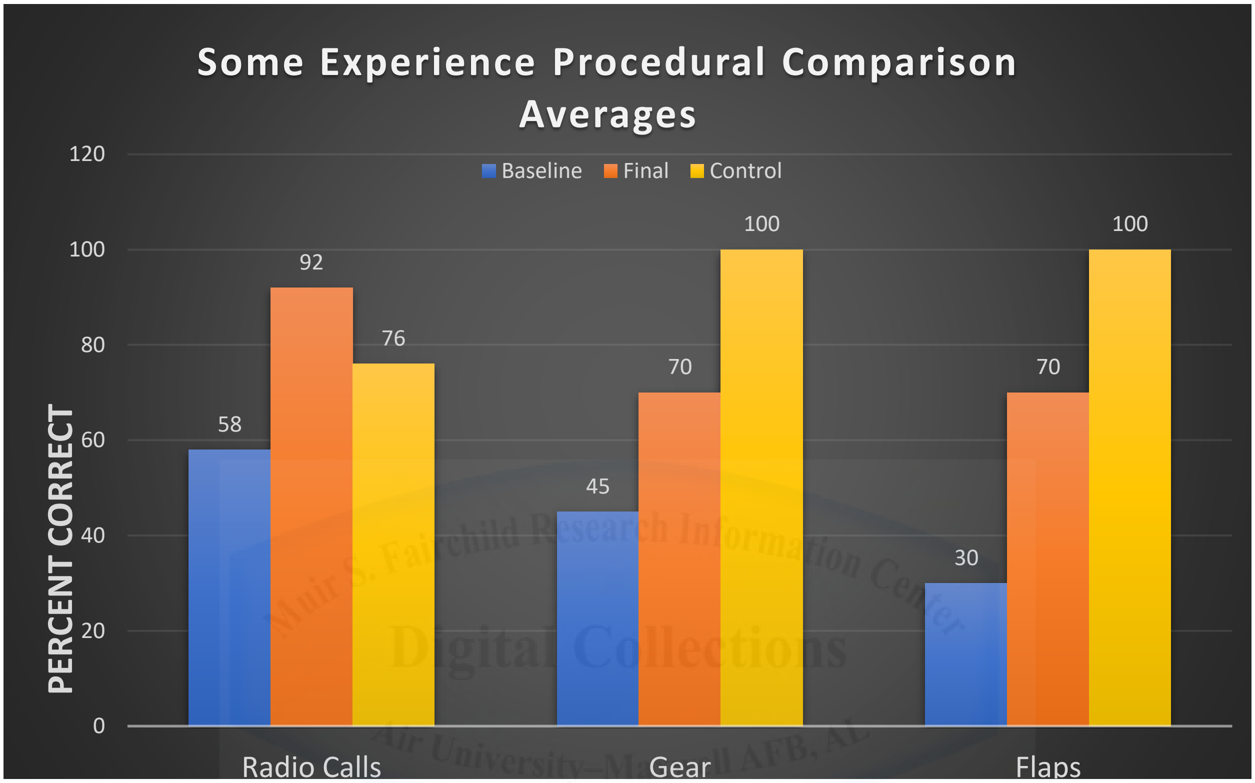

Figure 17. Comparison of Some Experience Average Procedural Completion Percentage

The some experience subgroup demonstrated improvement across all three categories. The average level of improvement was 33%. The most common failure for gear and flaps procedures was not a result of failing to activate the switches but failing to adhere to the requirement that they must be raised and lowered below 150 knots airspeed.

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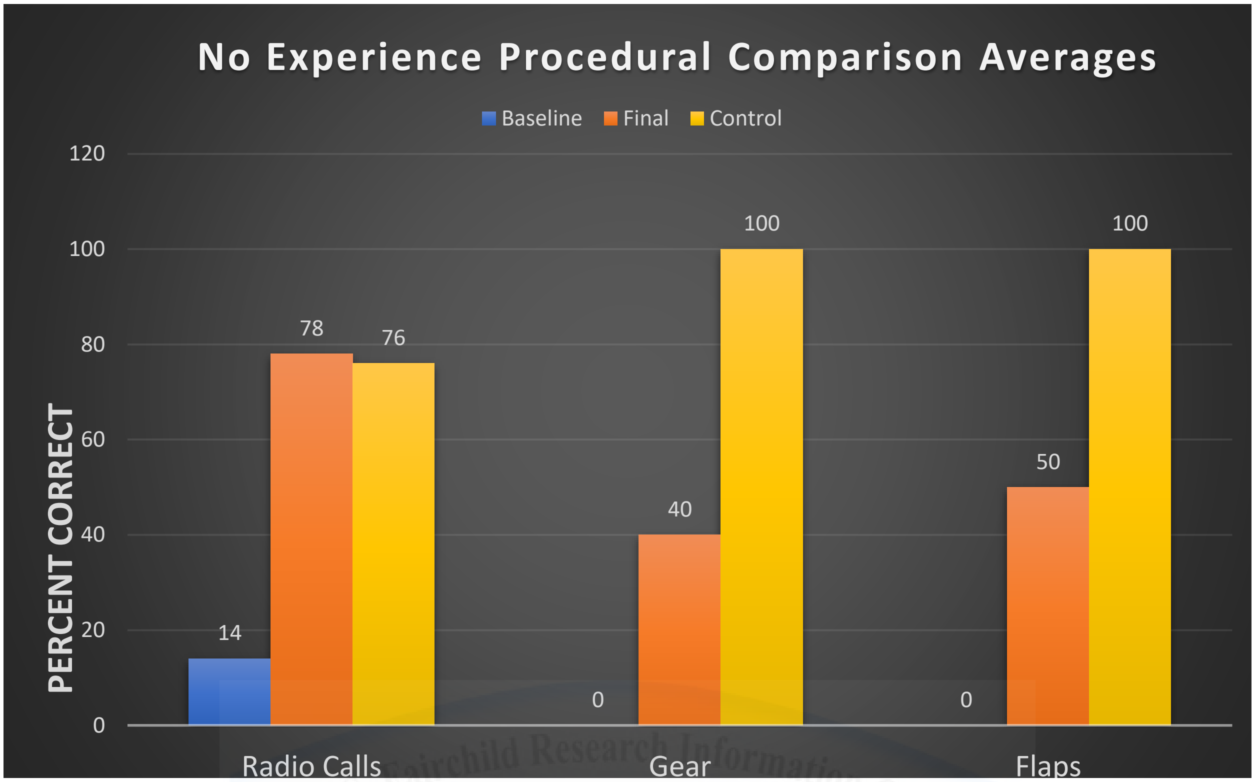

Figure 18. Comparison of No Experience Average Procedural Completion Percentage

The no experience subgroup demonstrated the greatest improvement with an average gain of 51% across all areas.

Kinesthetic Transference Results

Kinesthetic learning was evaluated using the subjects' flight performance during the OFT sorties using airspeed and altitude. Specifically, the deviations of the airspeed and altitude from 200 knots and 1200 feet were measured. Altitude and airspeed data were collected for the entire sortie but only measured for evaluation during straight and level parts of the pattern. This is because the aircraft is climbing to altitude and descending to land during the profile and standardizing a climb or descent rate is unrealistic and not something we had the resources to capture in this study. Both data sets started being evaluated after the first 90-degree turn, midway through upwind (approximate heading 210-240). This is the point when all subjects would be expected to be at 1200 feet and 200 knots. The evaluative portion continued airspeed until the subject started their break turn. At this point, the task procedure called for retarding the throttle to begin slowing down so measuring the airspeed delta was no longer feasible. We continued to evaluate the altitude control until the subjects rolled out on inside downwind (approximate heading 130-150). We evaluated the altitude throughout the break turn because it is a dynamic maneuver where subjects are accomplishing multiple kinesthetic and cognitive tasks and would provide an indicator of flying performance skill.

A final measurement evaluated was the total flight time from aircraft rotation to touchdown. During testing, the control group all flew very consistent patterns of +/- 10 seconds of total flight time from takeoff to touchdown. Total flight time for the sortie is not conclusive data, but it can indicate error rate because a perfectly flown pattern has an optimal flight time that includes perfectly flown airspeeds, altitudes, and ground-track (lateral distance in relation to the runway). In a three-dimensional space timing can be a valid indicator of performance, or at a minimum, it can indicate error rate because any deviation in airspeed, altitude, or lateral position changes the time. A longer sortie time could indicate a longer or wider ground track, deviations in altitude or a slow airspeed. Shorter sortie times could indicate a smaller ground track or a faster airspeed. While total flight time does not allow for specific errors to be identified, certain trends do tell a story. The control group flew an average total flight time of 379 seconds executing good airspeed control and an ideal ground track. The total flight time varied among test groups during the baseline assessment. The more experienced subjects trended towards a longer total flight time as they took a longer and safer ground track while getting a feel for the aircraft. The no experience subjects' total flight time average does not truly reflect their level of performance because some subjects crashed during takeoff (recording a flight time of 5-10 seconds) and some got lost and flew away from the airfield, eventually executing a pattern

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completely different than the one depicted in the provided task card and recording an excessively long flight time. During the final evaluation, all groups normalized closer to the total flight time of the control group, indicating that they flew a more ideal pattern ground track and airspeed. The average difference between test groups' average and the control group during the final evaluation was 7.3 seconds.

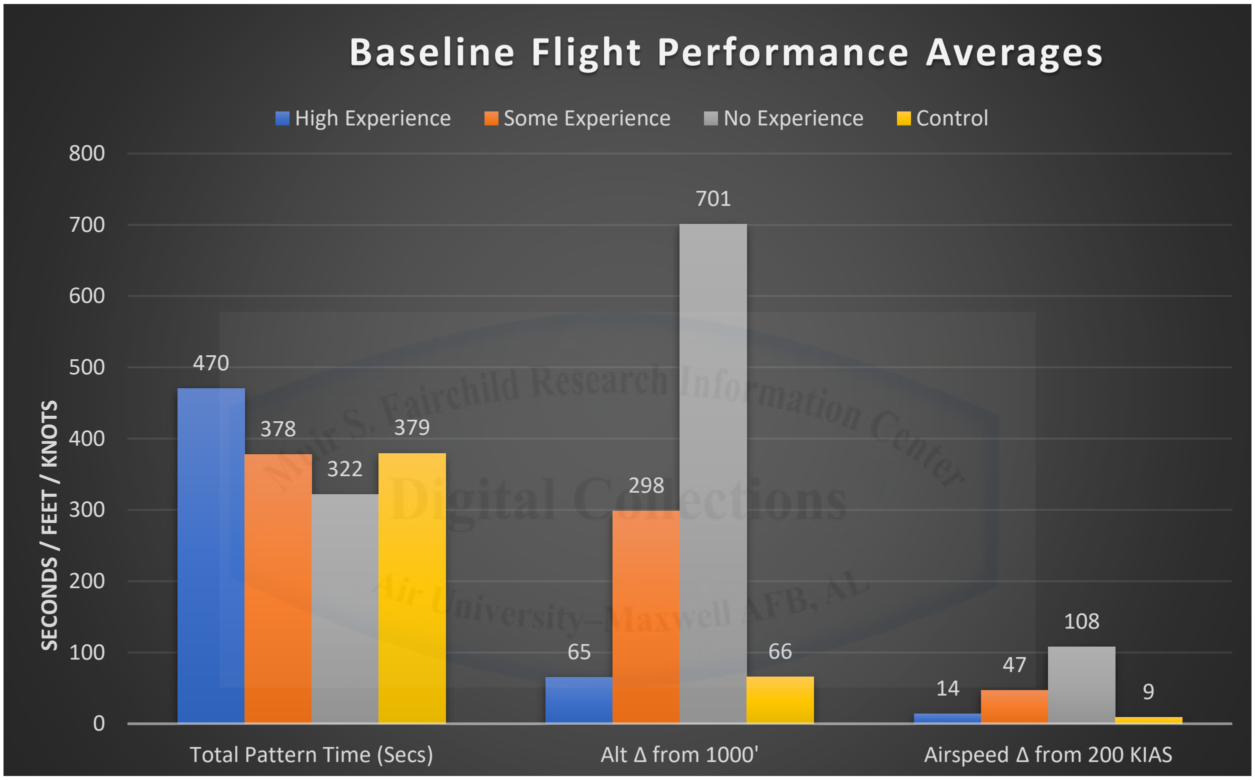

Figure 19. Comparison of Average Baseline Flight Performance, All Groups

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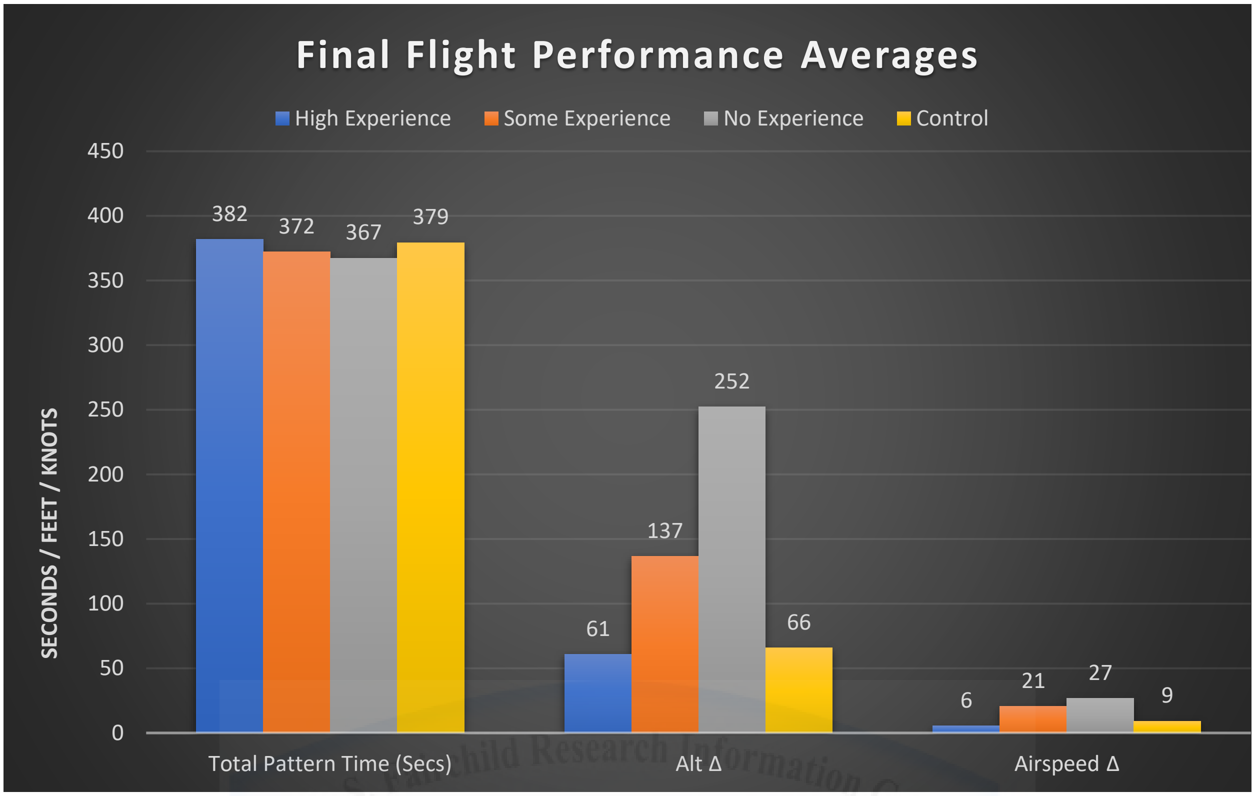

Figure 20. Comparison of Average Final Flight Performance, All Groups

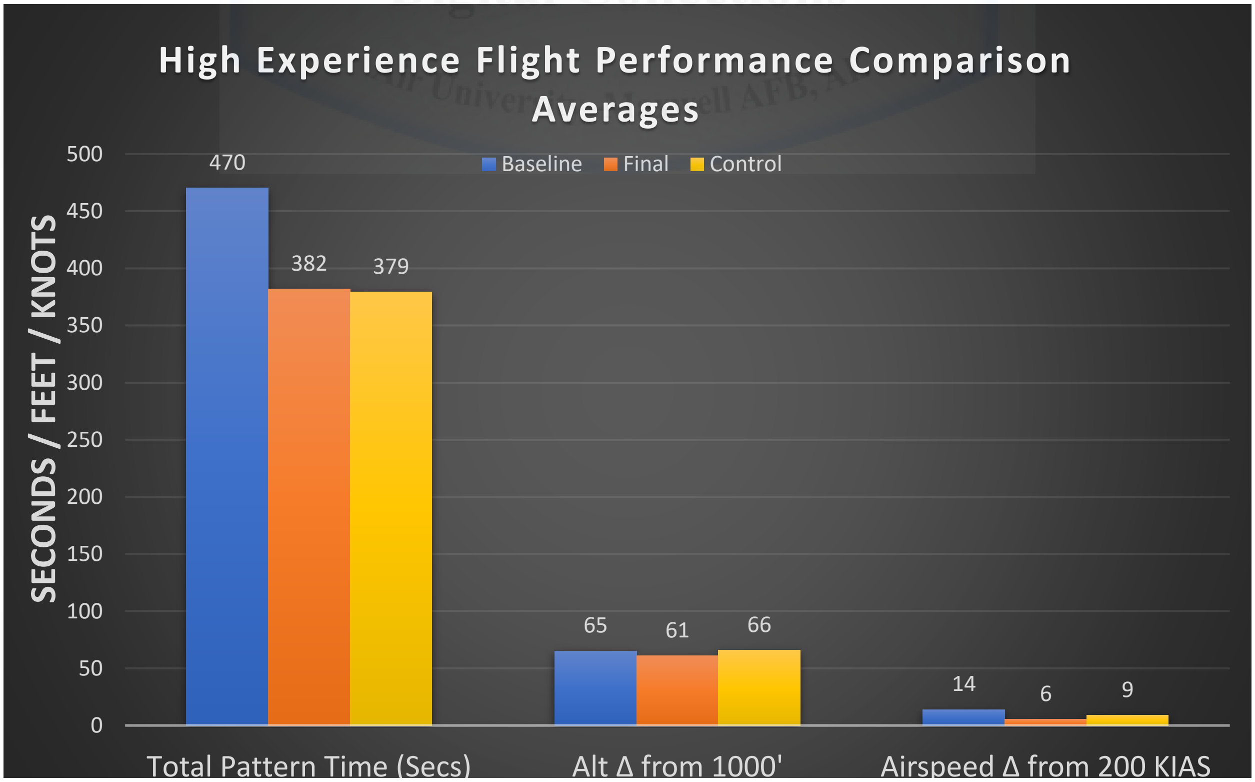

Figure 21. High Experience Comparison of Average Flight Performance

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The high experience subgroup showed improvement across all measured areas and even performed better than the control group in altitude and airspeed control. Greater than a minute improvement was demonstrated in total pattern time, potentially indicating a wider pattern flown during the baseline because the airspeed and altitude deviations were not significantly different from the control group to justify the longer pattern time. During the final evaluation the group flew a pattern more consistent with the control group.

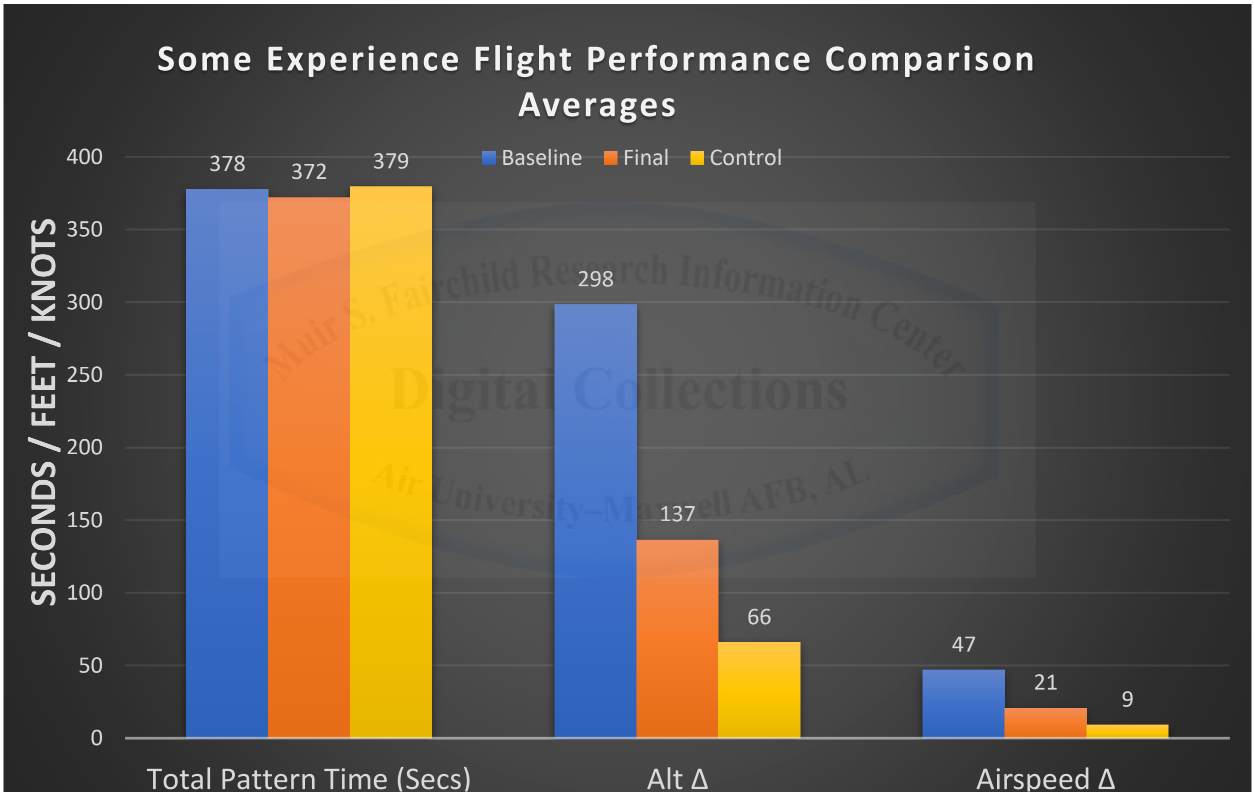

Figure 22. Some Experience Comparison of Average Flight Performance

The some experience subgroup demonstrated consistent total pattern times but showed improvements in altitude and airspeed control. Average altitude control improved by 161 feet and airspeed by 26 knots. The group did not improve to the point they executed on par with the control group or meet the UPT evaluation standard of +/- 100’ of altitude control and +/- 10 knots of airspeed control.

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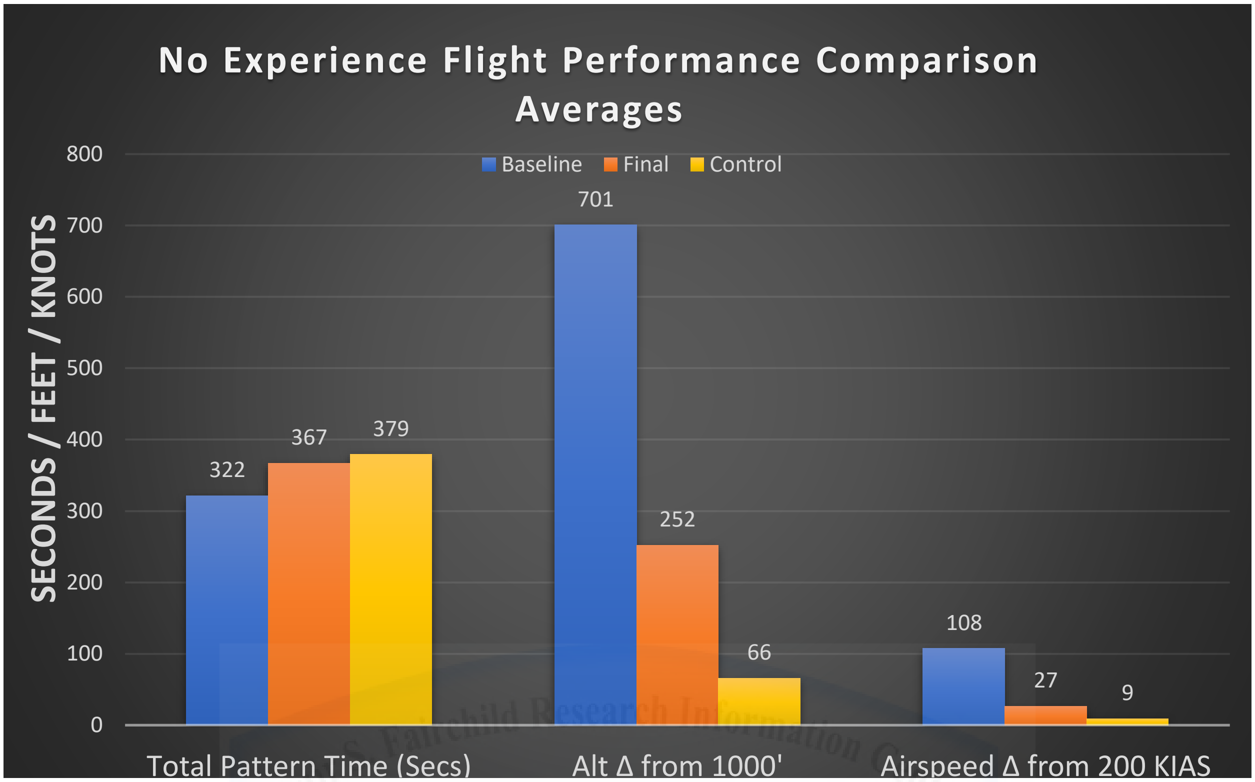

Figure 23. No Experience Comparison of Average Flight Performance

The no experienced subgroup demonstrated improvement in total pattern time, however, this is not an effective indicator because many crashed before completion of a full pattern during the baseline assessment which affected the overall average pattern time. Additionally, they showed improvement in altitude and airspeed control. Average altitude control improved by 449 feet and airspeed by 81 knots. Overall performance remained the worse of all the groups, however, they demonstrated the greatest level of improvement.

Subjective Performance Assessment

The subjective performance assessment was conducted by an experienced UPT Instructor Pilot acting as the observer in the OFT for the baseline and final evaluations (same instructor for both assessments). The instructor subjectively assigned a score of 1 (Very Weak) to 5 (Very Strong). This data is subjective; however, even though a 1 to 5 scale is not used, the subjective nature is consistent with how USAF pilots are evaluated during training and annual evaluations. Therefore, significant consideration is given to the Instructor Pilot’s assessment of the subjects.

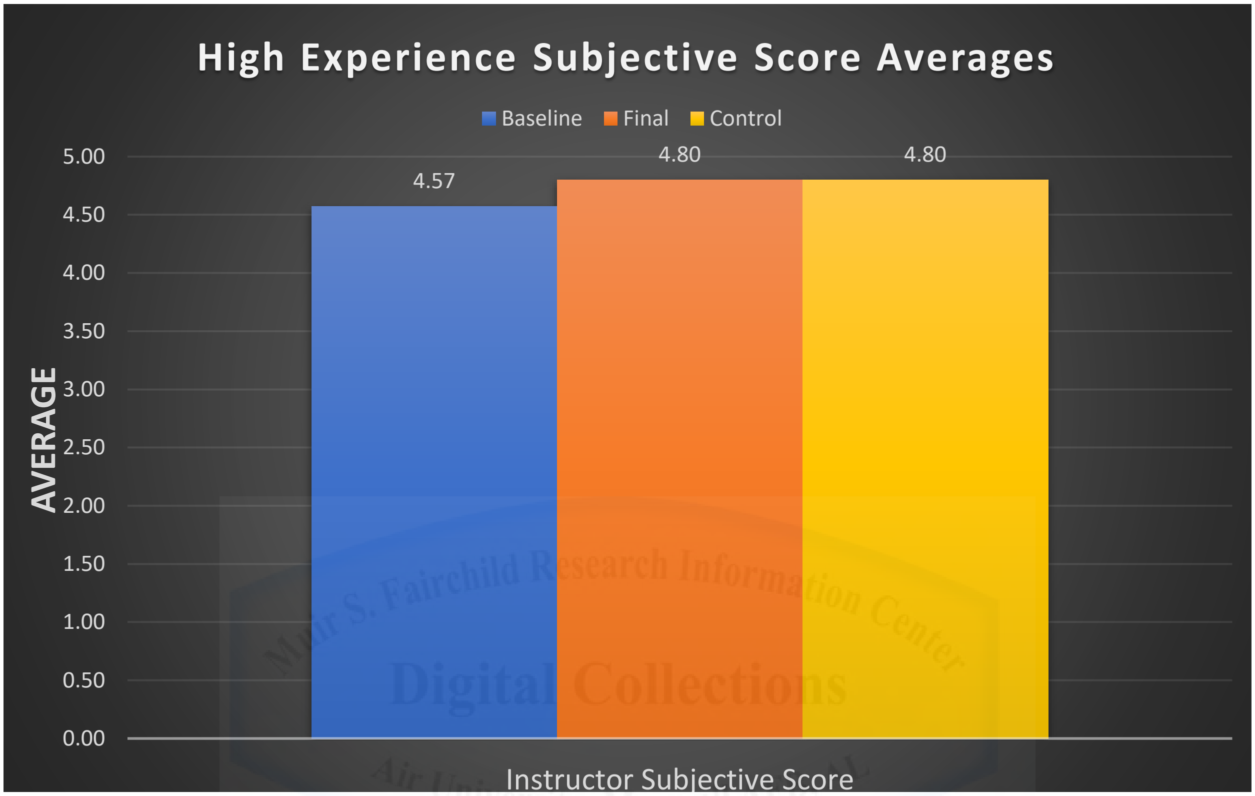

Figure 24. High Experience Average Subjective Score

The high experience subgroup showed a slight average score improvement from the baseline to final evaluation. The average score on the final evaluation matched the performance of the control group.

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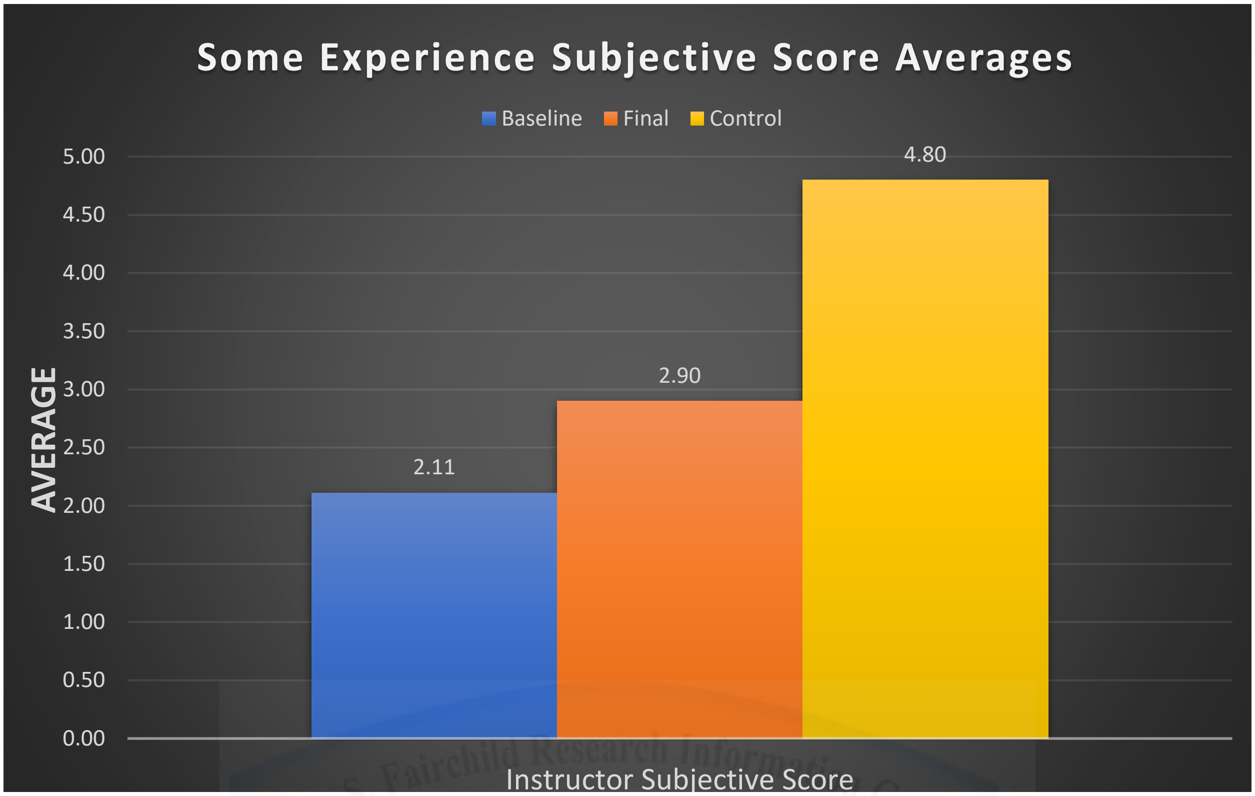

Figure 25. Some Experience Average Subjective Score

The some experience subgroup showed an average score improvement from the baseline to final evaluation.

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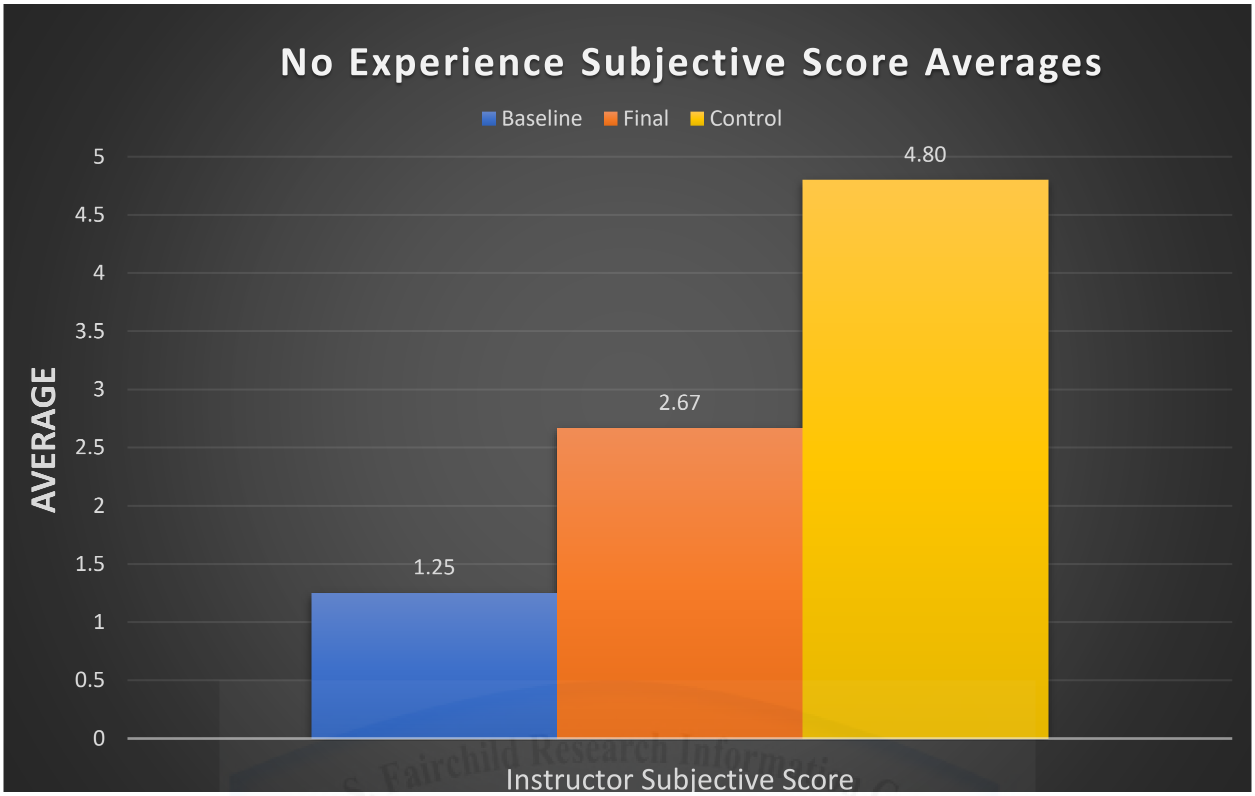

Figure 26. No Experience Average Subjective Score

The no experience subgroup showed the greatest average improvement from the baseline to the final evaluation.

Biometric Results

Biometrics data captured during the study were Cognitive Load, Arousal Factors (Heart and Respiration Rate), Eye Movement and Eye Tracking.

Cognitive Load

Cognitive load or neurological activity was measured through the eye using a Pupil Labs camera and calculated with a Senseye proprietary algorithm on a scale of .001 to 1. Cognitive load measurements data was only captured from the VRLE sorties because the cameras used in the OFT evaluations did not capture data with the required fidelity to run the algorithm. Despite the best efforts to ensure a good recording before commencing the test, the glasses holding the camera were not as secure as the VR headsets and subjects' head movements negatively affected the quality of the recordings.

One of the biggest issues with cognitive load is that a subject's cognitive baseline changes daily and is specific to the individual. This makes relative comparisons between different days and between individual subjects impossible. To help alleviate this problem each subject established a baseline before the task began. After the 10 second relaxation period discussed in previous sections, the system took a 5-second snapshot of their cognitive load before they began flying the aircraft to serve as the baseline for that sortie. Only data collected on the same day for each subject was analyzed and compared to their performance that day. Although correlated cognitive load with specific activities was not possible, overall trends and indicators were able to be identified across all subjects.

Subjects displayed trends of increased cognitive load during periods of increased workloads, especially during critical phases of flight such as takeoffs, landings, and transition periods when subjects were changing airspeeds, configurations, or making radio calls. Additionally, the debriefing tool consistently displayed spikes in cognitive load when subjects deviated from the assigned airspeed or altitude which could indicate task saturation or poor prioritization of task management. Overall, the cognitive load average was 0.477, and optimized performance occurred around the neurological activity measurements of approximately 0.30-0.40. Anything above 0.60 resulted in below average performance. Also, subjects with higher cognitive loads often had longer eye fixation times or slower saccades. Saccades "are rapid, ballistic movements of the eyes that abruptly change the point of fixation."[58] The data was not analyzed with the level of detail needed to make accurate activity correlations for each individual between their cognitive load and their performance.

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Three future applications of cognitive load measurements would be cognitive optimization for learning, cognitive comparison for task mastery, and cognitive inoculation for unexpected experiences. Cognitive optimization is the peak performance periods of neurological activity that allows students to learn the most and perform at their best. Dr. John Sweller’s study of cognitive science describes cognitive load and its relation learning. "Cognitive load relates to the amount of information that working memory can hold at one time. Since working memory has a limited capacity, instructional methods should avoid overloading it with additional activities that don't directly contribute to learning.”[59] Cognitive optimization would be unique to each person and change daily due to a multitude of variables such as sleep, nutrition, life stressors or situational pressures. The challenge of baselining the measurement is a problem that must be solved to make this capability useful. Cognitive comparison for mastery is the difference in cognitive load while completing the same task in the same conditions. The possibility exists to tell if someone mastered a task by measuring the differences in their cognitive load between training sessions about the required task performance. Lastly, specifically looking at the rate or slope of change in a subject’s cognitive load during unexpected experiences could indicate the level of cognitive inoculation or calmness which would provide indications of that subject’s ability to operate better in future chaotic and uncertain environments.

Arousal Factor

Arousal factor was measured with the help of Air Force Research Labs using Zephyr Bands on 15 of the 30 subjects that captured heart beats per minute (bpm) and respirations per minute (rpm). The Zephyr Bands were worn by subjects in the OFT and AFT.

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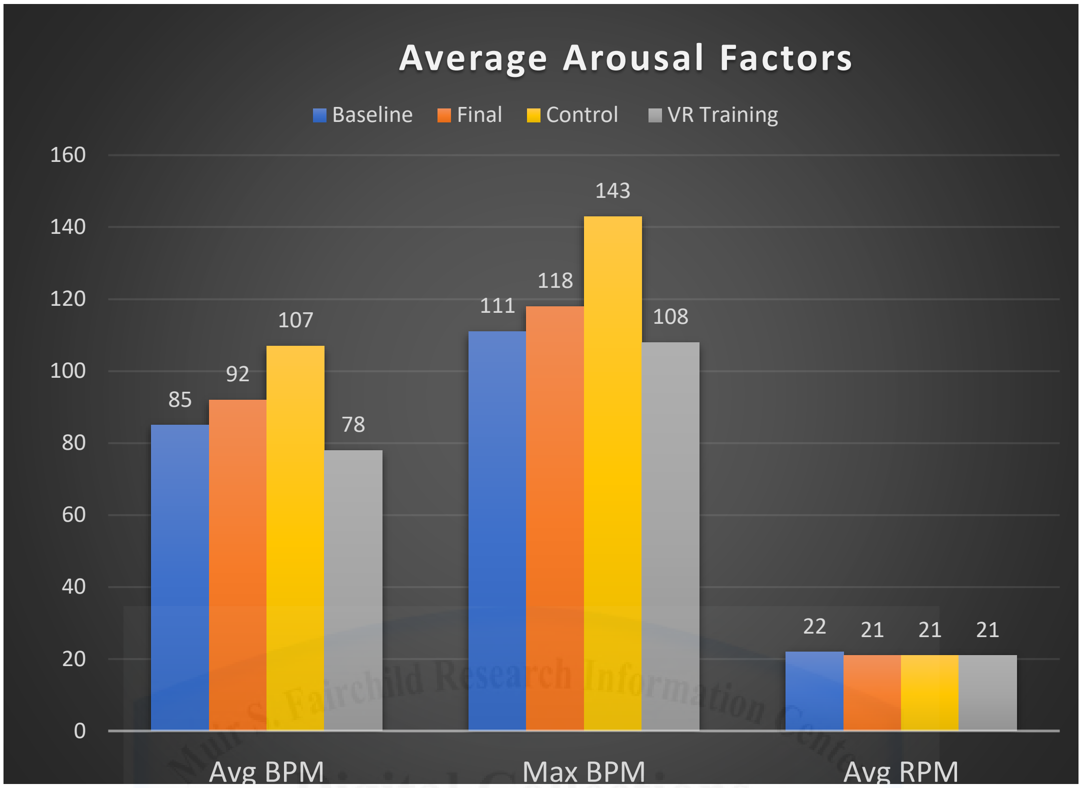

Figure 27. Average Arousal Factors

Average heart rate and average max heart rate for subjects increased between the baseline and final evaluation by an average of seven bpm with negligible change in rpm. Compared to the control group average and max bpm were significantly lower during all OFT evaluations, and the difference in average rpm was negligible. The difference in arousal between the control group and the other subjects could be due to increased pressure to perform. The members of the control group were the only participants currently in an actual pilot training pipeline and inherently experienced stress in the OFT because all aspects of UPT are graded and affect follow-on assignments. This possibility was not considered by the research team, so the control group was not sufficiently briefed about the non-attributional nature of the test. The incomplete sample size could have also played a factor in the differences because only half of the subjects wore Zephyr Bands to measure arousal factors.

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Another trend was the difference in heart rate between the OFT evaluations and the VRLE. The heart rates measured in VRLE never reached the same level as they did in the simulator, maintaining on average 7-14 bpm lower during VR training. Two possible causes could be that flights in the OFT were being evaluated and each student's performance was being observed and measured by multiple people increasing the stress factor. Whereas the flights in VRLE were "student-centered." They were being monitored, but the student was in charge of their progress and experience. There was no pressure fromevaluation during flights in the VRLE. Another reason could be that the VRLE was not as immersive as the OFT,however, the qualitative affective assessments filled out by the subjects indicated that the VRLE was equally immersive, but their assessment could be partly due to the novelty of the technology. Overall, there was an increase in heart rate during immersion in the VRLE versus average resting heart rate, increasing on average between 15-18 bpm during VR flight training. This increase in heart rate confirms arousal and immersion in VRLE. Due to timestamp issues and activity verification, heart rate and arousal factors in relation to specific phases of flight during the sorties could not be analyzed with any fidelity, thus the reliance on average heart and respiration rates. This was one of the previously mentioned limitations of having multiple data streams not captured in parallel.

Eye Movement and Tracking

Eye movement and tracking measurements recorded the time between points of fixation and captured the object the fixation was focused on during the flight training in the VRLE. The eye tracking measurements captured what object the eye was focused on and is more in line with cognitive perception. "Straightforwardly, eye movements provide a multifaceted measure of performance. For example, the location of fixations, their duration, time of occurrence, and accuracy all are potentially revealing and often allow stronger inferences than measures such as percentage correct or reaction time. Another advantage is that eye movements are an implicit measure of performance and do not necessarily involve conscious processes.”[60] For pilots, the fixation sequence or crosscheck has always been a very important aspect of performance. Eye movement and eye tracking measurements for this study were only conducted in the VRLE due to a malfunction with the eye tracking cameras during the OFT evaluations.

Eye movement and eye tracking measurements did provide trends that should be explored further in future studies. Slower eye-movement or longer static gaze length was an indicator of poorer flight performance to include airspeed and altitude control. The longest measured average gaze length was 9.7 seconds for a training sortie. Shorter gaze lengths or faster eye movements indicated better performance for most test subjects. Across all sub-groups when the gaze length was 0.3 or less, performance was above average. The average gaze length for all subjects was 0.66. The fact that test subjects trained in VRLEs with three different levels of guidance distorted some of the eye movement measurements. In level 1 and level 2, there were guidance cues in the sky out in front of the airplane that helped guide them around the pattern and to maintain proper position in the three-dimensional space. Subjects tended to channelize on these visual cues for longer periods of time which affected gaze lengths. Level 3 had no guidance cues and provided the best opportunity to understand the impact of gaze length. Overall, those with a faster cross check or shorter gaze length had better performance and progressed more quickly through the VR flight training levels. Future implications of eye movement and eye tracking capability could provide educators or instructors with a higher fidelity of understanding concerning a student’s performance and their level of proficiency at the task being conducted.

Columbus AFB AFT Analysis

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Analysis of this study is two parts. First, the authors of the study provide “Observed Indicators and Outcomes,” that are the result of raw data and very little statistical analysis. Second, Senseye Incorporated’s cognitive and data scientists provided a linear, a quadratic and a machine learning statistical regression analysis.

Observed Indicators and Outcomes

The Columbus AFB AFT study did provide multiple indicators, trends, and verified flight performance improvements that were a result of kinesthetic and cognitive transference from the VRLE to a real-world T-6A certified simulator. All sub-groups (no aviation experience, some aviation experience, and high aviation experience) improved airspeed control, altitude control, and execution of procedural tasks. After 1.5 hours of student-centered VR training in the AFT, the average improvement across all sub-groups was 38 knots of airspeed and 205 feet of altitude control as well as 30% improvement in procedural task completion. Subjectively all-sub groups improved an average of 14% as measured by the Columbus AFB T-6A Instructor Pilot during observations of the baseline and final OFT evaluations. The T-6A instructor graded the students with the standards they use for actual students they would be evaluating or instructing during normal T-6A training.

The study also indicates there are linkages between cognitive load, arousal factors, and eye measurements. These linkages should be explored at a greater depth with more scientific rigor to enable more accurate feedback loops and stronger data sets. The high experience sub-group had the least relative increase in performance but had the smallest room for improvement. The no experience sub-group also had the steepest learning curve and achieved better performance faster than any of the other subgroups. On average it took the high experience sub-group 3-4 training sorties in the VRLE to master the required task. Whereas the some-experience sub-group never reached the same level of mastery but began to have an acceptable performance of +/- 100 feet and +/- 10 knots of airspeed after 6-8 rides in the VRLE showing a slightly slower learning curve. The no-experience sub-group never did reach an acceptable level of performance in approximately 10 rides, but they did reduce their crash rate by 50% in their final evaluation. The no-experience sub-group also had the greatest improvement overall. They improved 288 feet in altitude control, 55 knots in airspeed control, and increased procedural task completion by 18%, this was more than the other two sub-groups combined. All sub-groups migrated toward the control group indicating overall improvement.

The AFT was able to produce cognitive and kinesthetic transference from a VRLE to a real-world execution of the task within 1.5 hours of training indicating the potential validity of the TLST. With greater scientific rigor and more iterations, the TLST could be further refined and validated. Furthermore, it could be applied to different educational tools and curriculums redefining education and training by creating a structure that is more ergonomic to native digital learners and more elastic to changing and uncertain environments. All indications are that the TLST provides knowledge and skill accumulation at a value unseen in current systems used by the USAF. The TLST also provides design flexibility and data capture that allows organizations to adjust their education and training needs to the emerging demands of future operating environments.

Statistical and Machine Learning Indicators and Outcomes

The following information and analysis were provided by Senseye Incorporated's cognitive and data scientists to provide a starting point for a more scientifically rigorous study in the future. Due to the limited number of participants from a convenience sample, the following information and analysis are meant to be informative and not deterministic in nature. Senseye

Inc. developed three preliminary models from the VRLE, a linear model, a quadratic model, and a machine learning algorithm to create predictive models for VRLE performance using data collected from the Columbus AFB AFT test. No data from the T-6A baseline or final OFT evaluations were used in the following models because of incomplete datasets. The T-6A OFT datasets were missing cognitive load and eye tracking biometric measurements due to a malfunction in the cameras used during the OFT portions of the test. The linear model provides a perspective on how the biological variables and experience predicted performance in the VRLE. The performance score for the linear model was created by combining the performance measures of altitude, airspeed, number of successful radio calls, and raising and lowering gear and flaps. These measures were computed as a percentage. Each component was equally weighted then averaged together for an overall percentage of performance. Performance percentage for this linear model ranged from 40 to 89, with a mean of 71.

Correlations and Scatter Plots

The linear model used variables of prior aviation experience, eye-movement, average cognitive load, average heart rate, and average breath rate to correlate each variable with performance average and to check for any inter-correlations between them, before testing various linear models.

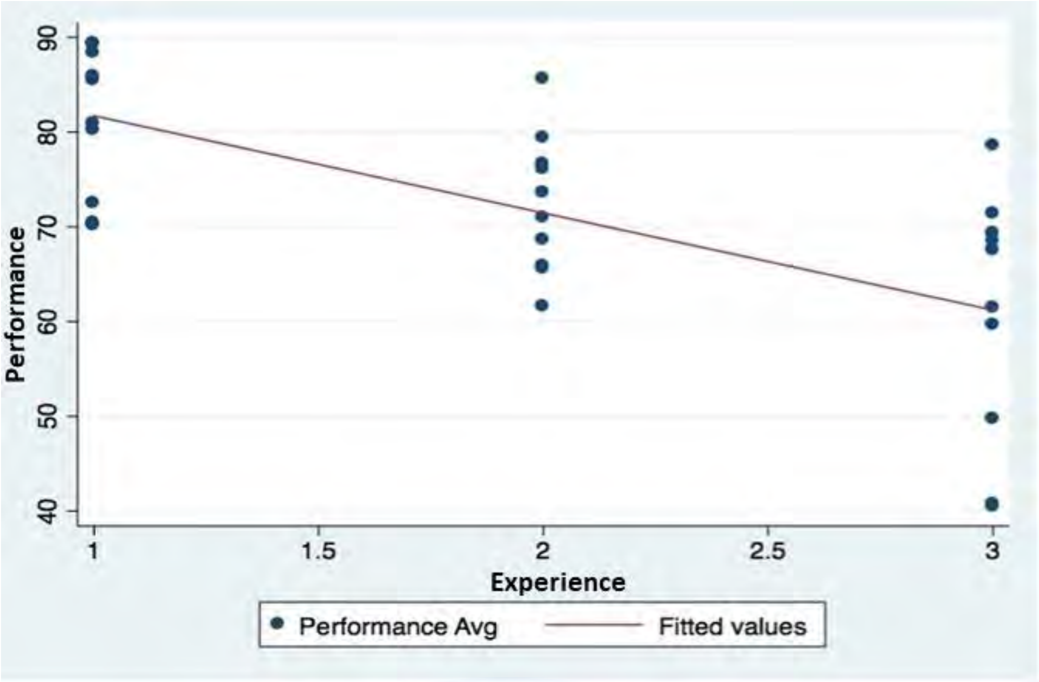

Figure 28. Scatter Plot of Performance and Experience

In Figure 28, prior aviation experience is presented on the x-axis from the left (most experience) to the right (no experience). The #1 represents experienced pilots, #2 represents some experience, and #3 represents no-experience. Pilot experience and performance had a correlation of 0.67, the most of any variable.

Figure 29 below represents the correlation between performance and biological factors. As the eye-movement time and cognitive load average increase, subject's performance increases. Eye-movement average and cognitive load also show large clusters around the mean of performance 0.71. Conversely, as breathing rate and heart rate average increase, performance decreases. During an interview with Dr. Andy Stricker, he provided his analysis of the data correlations. He has over 30 years of work in this field and his comments are as follows: "Results depicted in Figure 29 do not fully represent nonlinear relationships between visual demands and cognitive load. Performing a visually demanding secondary task (e.g. radio calls and preparation for final approach) concurrently with flying the aircraft, results in time sharing of visual resources between the two tasks. The visual demand imposed by secondary tasks can be directly quantified by means of eye movement measures, for example glance frequency and mean duration. The effects of visual time sharing on flying performance have been extensively studied and are well understood. Visual secondary tasks have also been demonstrated to impede signal-event detection performance. Thus, cognitive load assessments using eye-tracking movement is not a simple function of secondary task demand but rather involves a complex relationship between primary task demand, secondary task demands, pilot characteristics, and the effort invested in the different tasks. It is important to highlight the results depicted in Figure 29 follows closely to what has been proved in past studies that cardiac activity, measured in heart rate and heart rate variability, is sensitive to mental workload and stress. Overall, results from this exploratory study upheld expectations that visually and cognitively loading secondary tasks have differential effects on flying performance across levels of experience whether taking place in real-flight or simulated contexts. Consequently, gains observed across all groups in the study followed expected patterns of physiological and performance effects and suggest beneficial usage of eye-movement measures with VR-pilot simulators for future flight training regimens making use of adaptive tutoring features with the means to track and provide feedback uniquely suitable for each pilot trainee." Outliers are included in this calculation due to the small sample size.

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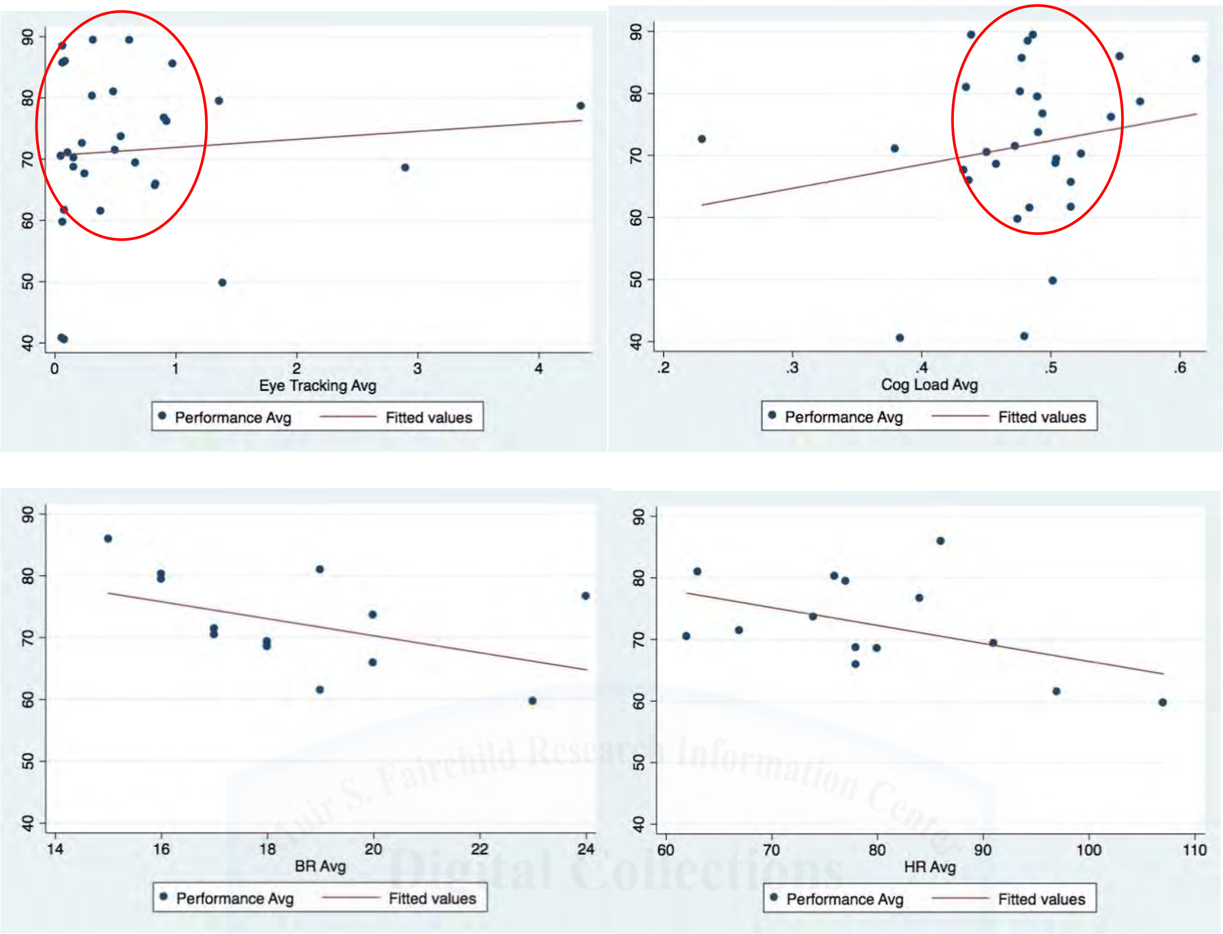

Figure 29. Biometric Scatter Plots

Linear Model

The linear model with the best fit incorporated pilot experience, their average heart rate, their average eye-movement time, and average cognitive load to predict performance. This model produced an adjusted R-squared of 0.69, which means that about 70% of the variance in average performance between pilots was captured by the linear model. The predicted calculation versus actual values is displayed in Figure 30.

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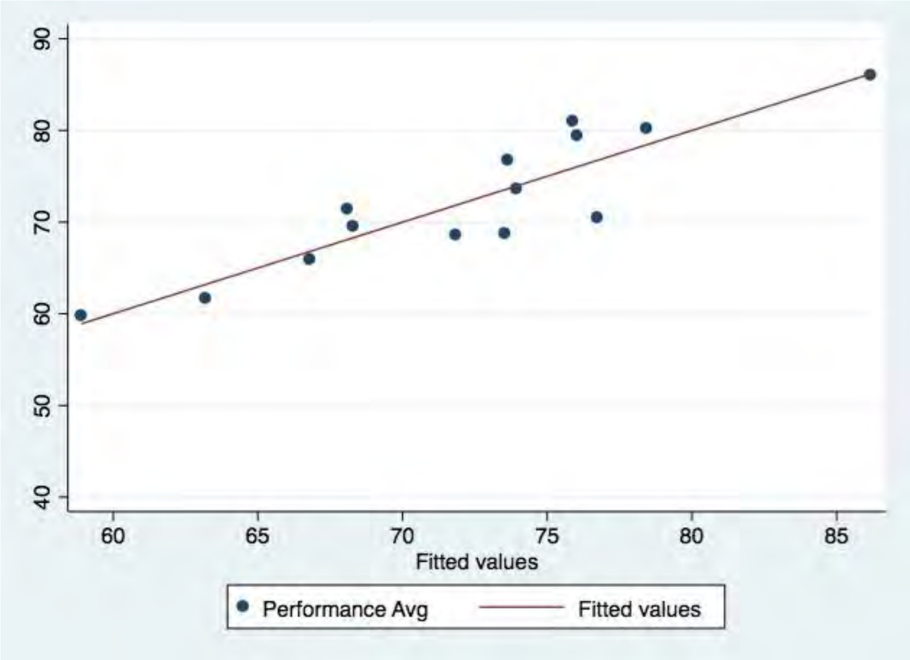

Figure 30. Fitted Model with Outliers

The variables with the highest coefficients and t-values and with the most predictive value were pilot experience and cognitive load. Statistically eye-movement time and heart rate had the next highest coefficients and t-values. Heart rate and respiration rate had high correlations to each other, decreasing their predictive value. Only half (15) of the Columbus AFB AFT study subjects had respiration and heart data making the dataset partially incomplete. The model represents predictive value for VRLE performance using experience, cognitive load, eye-movement, and heart-rate. The encouraging factor is that the small sample of data collected formed a predictive model of performance and suggested there are correlations that exist that should be explored further.

Quadratic Fit of Eye Movement and Cognitive Load

Though the regression model functioned well, clusters indicate that the effects of eye movement and cognitive load followed a polynomial pattern. To make this pattern clearer, two outliers (subject’s whose data was beyond 2.5 standard deviations from the mean) were identified and removed from the eye-tracking movement values, and the cognitive load values.

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An increase in average eye-movement indicated increased performance only up to a point (Figure 31). After a length of about 0.75 seconds gaze length, the performance begins to decrease. The grey section surrounding this line represents the area that 95% of future expected values would fall under repeated experiments. As the eye-movement increases, the performance decreases and the confidence in the model becomes more uncertain. This indicates that there is most likely an optimal eye-movement time but more data is needed to solidify this quadratic result.

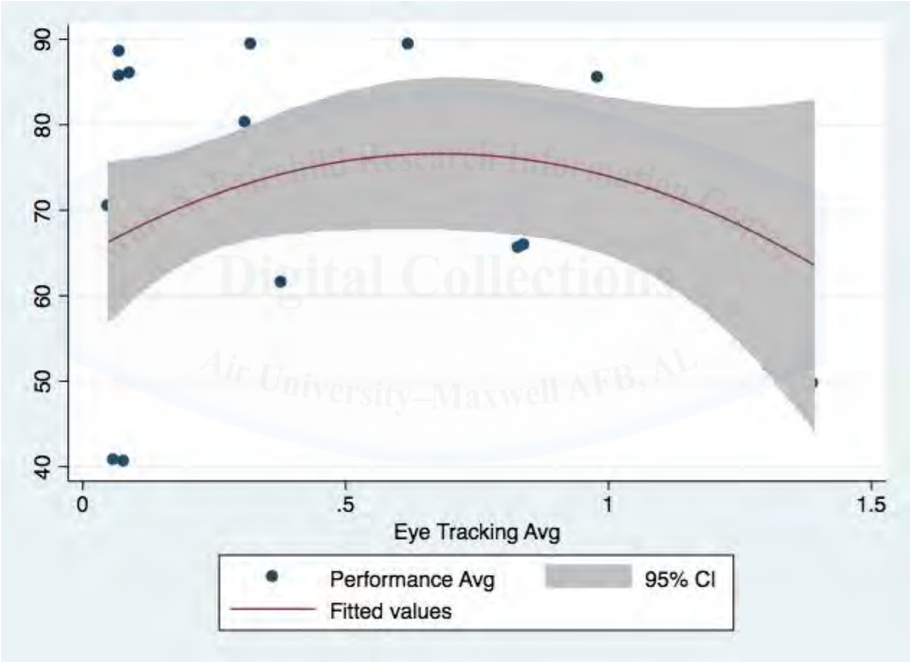

Figure 31. Cognitive Load Quadratic Model

A similar pattern is evident for cognitive load. Increasing cognitive load predicts increased performance, up to 0.5 (Figure 32). After 0.5 the high cognitive load likely indicates that the subject is overtaxed, and performance begins to show diminishing returns. The wide intervals at the ends of the cognitive load scale indicate that more data from subjects who display high or low cognitive loads in these areas would solidify this model.

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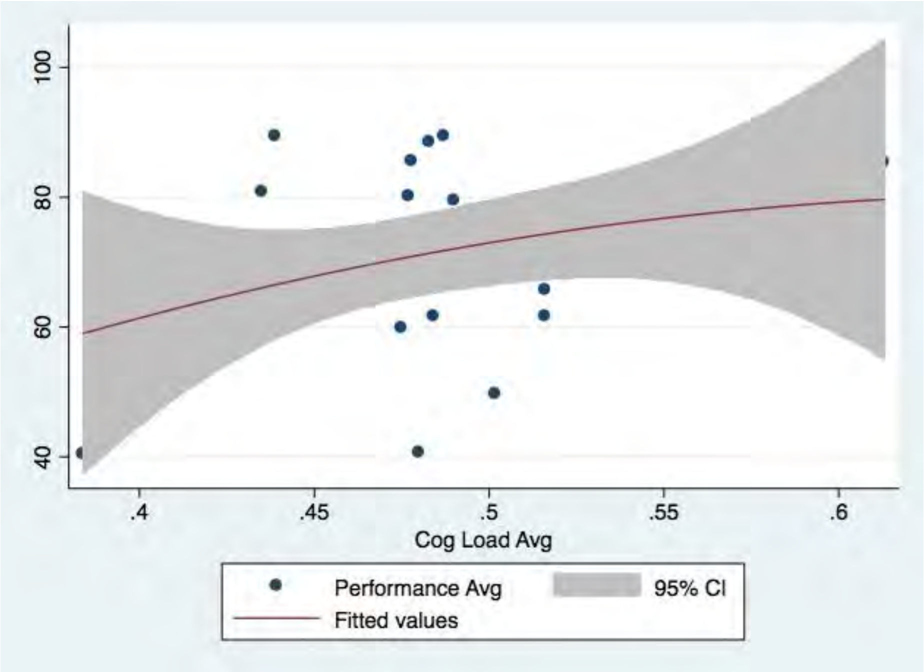

Figure 32. Eye Movement Quadratic Model

Finally, another predictive model was generated using the updated weights for eye-movement and cognitive load (Figure 33). This model disregarded subject’s eye-tracking and cognitive load data that was beyond 2.5 standard deviations from the mean of each variable as indicated earlier. The new model accounted for a high amount of the variance as represented in the performance average of Adjusted R = 0.85. The below model fits predicted values to actual values more closely than the previous model, indicating a stronger model after disregarding outliers. The limited number of subjects make this model volatile, and it is important to understand that elements of the model may change rapidly as more data is collected.

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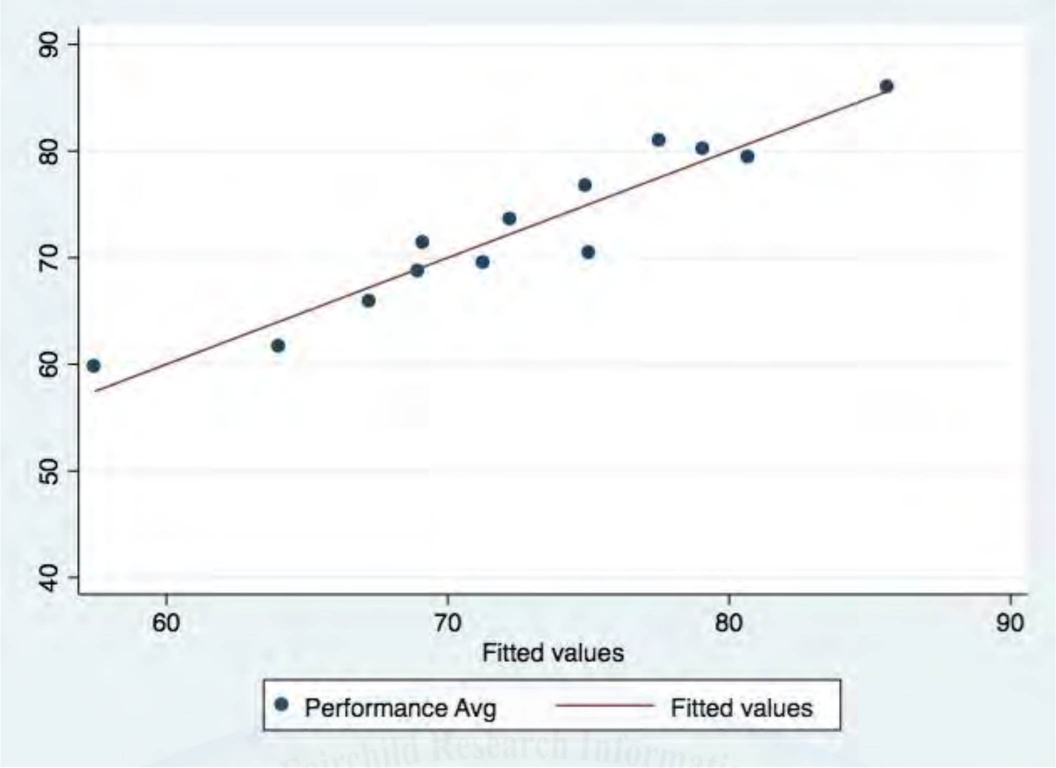

Figure 33. Fitted Model without Outliers

Machine Learning Algorithm

Senseye Inc. also created a machine learning algorithm for the post data analysis of the AFT test to predict human behavior and performance. The decision to use a Long Short-Term Memory Unit (LSTM) Neural Network was decided by Senseye's data-scientist because of the limited time and minimal dataset. They attempted multiple variations of inputs, weights, and hidden nodes for LSTM models, but ultimately an LTSM model with 16 input nodes, 50 hidden nodes, and one output node produced the best results in a couple of months allocated to developing a predictive model.

The specific model developed by Senseye Inc. attempted to do two things with the results of the AFT test. First, find out which biological factor was the most determinate factor related to performance. Second, predict a pilot's future performance by looking at current performance. The predictive model for flight performance used the biological inputs of cognitive load, eye gaze lengths, respiration rates, and heart rates. Senseye data-scientists used Keras to create and train the LTSM model. They trained the model over 50 epochs using 'Adam' optimizer from Keras.

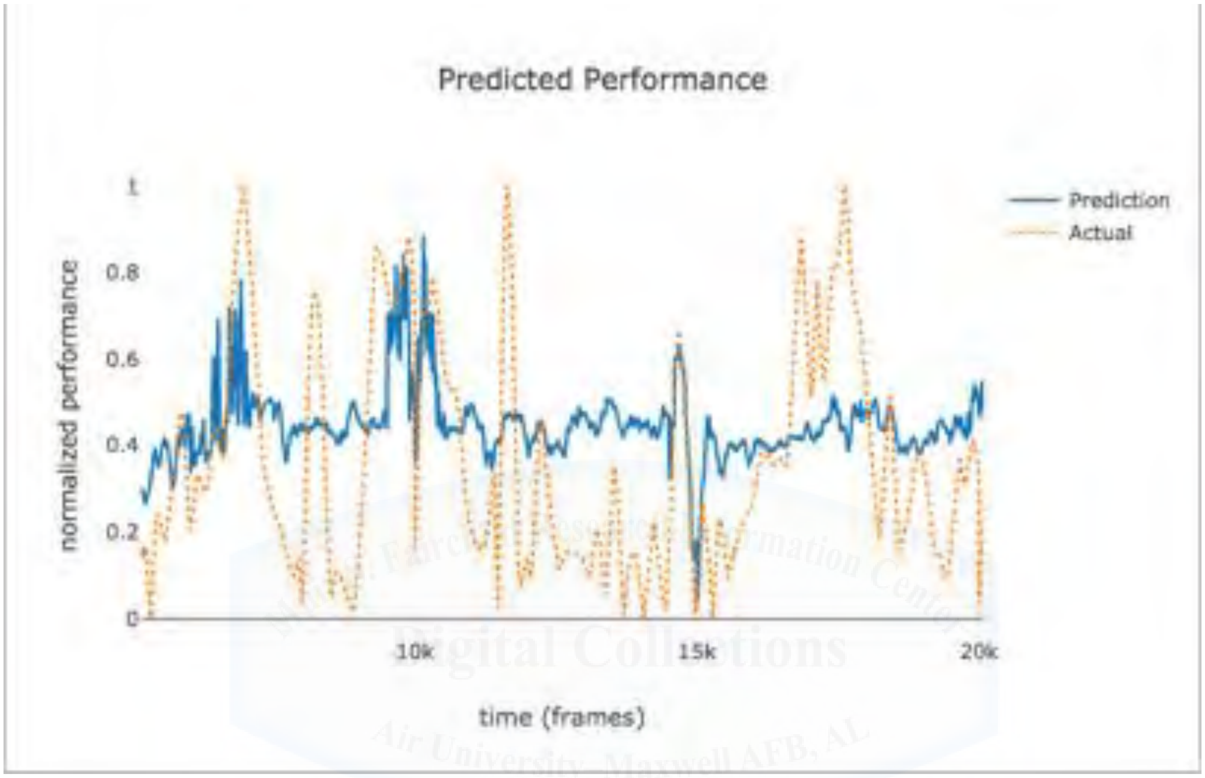

Figure 34. LSTM Predicted Performance

As depicted in Figure 34, the LSTM model was able to successfully predict some spikes and dips in performance, but overall the model is still very immature and underdeveloped. The model found correlations with breath rate, cognitive load, and performance at 0.2 certainty. Senseye Inc. said that "To determine if those are an artifact of overfitting or are true, a larger data set is needed." The model needs more refinement and data to predict performance with any real certainty. The metric of performance also needs to be more holistically represented and defined.

Performance for this LTSM dataset was a pilot's ability to maintain required airspeeds and altitudes. Any deviation from assigned airspeed and altitude resulted in a performance

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decrease. Perfect performance is perfect airspeed and altitude control. Senseye Inc. data-scientist also recommend more inputs. They recommend “giving it as many data streams as possible” to help better predict performance. Some potential data inputs include eye focal point position to know what they are looking at instead of just how long they look at something, joystick position, throttle position, and response times to correct for errors. Also, a more scientific and sterile test is necessary to make sure the biological responses are not associated with any other factors such as evaluations, distractions, or on-going stress.

A future study that provides more data and more scientific rigor with an emphasis on biological factors does have the potential to further develop these predictive performance tools. A predictive capability could be used for a multitude of organizational purposes from pilot candidate selection to alerting pilots where their attention should be directed. These tools help humans prioritize information and tasks. In the end, it is about helping humans make better decisions faster. In the simplest form, this is human-machine integration because it combines the curiosity, imagination, and situational awareness of humans with the power of machines that sorts data and prioritizes the presentation of variables.

Strategic Opportunities

The TLST presents both short-term applications and long-term opportunities for the USAF. Short-term applications include using empowering structures paired with technologically advanced learning devices to experimentally mature educational and training capability. Throughout this study inquiry and interest on utilizing this technology has come from multiple organizations to include: Civil Air Patrol, Reserve Officer Training Corps, Star-Base DOD, Squadron Officer School, Security Forces, Rescue Helicopters, Air Traffic Controllers, and Cyber Operator training. All of these exists as short-term opportunities for the USAF to provide

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means or ways to help these organizations reach their desired end-states. Beyond a training device, the novelty of the AFT system makes it attractive to use for flight introduction as well as recruiting possibilities.

In the immediate future, additional studies need to be conducted to further validate the effectiveness of the TLST and AFT while also looking at applications of TLST outside pilot training. Prototypes need to be put in the hands of operators and practitioners, so they can start experimenting with how to best maximize training potential through curriculum development. A simple follow-on study would be to place an AFT in every UPT flight room in one of the two T-6A squadrons at Columbus AFB. Give the students and instructor pilots free reign to experiment and use it as they see fit, no restrictions. As each class leaves the T-6A phase of training conduct a qualitative analysis of the AFT's value to training compared to classes following the traditional training curriculum in the other squadron. Also, capture how it was used by both instructors and students and provide that information to Pilot Training Next to further inform their operations.

Long-term opportunities provide the USAF the chance to iteratively improve this type of fused technology to assist in a more strategic full-spectrum approach. When enough data is collected, the tools created using the TLST could identify traits and patterns that make a pilot more successful, aid in pilot candidate selections and improve predictive analytics for student success. Switching to a performance-based model that allows for self-directed learning through iterative growth could reduce the number of physical flight sorties required to master a skill, driving down training costs. With further development, the TLST could be used to revolutionize personal growth opportunities and workforce development along a range of education, training, and learning especially as technology continues to advance at a rapid pace. Furthermore, the TLST has the potential to change how talent management is done by capturing a digital representation of a person’s professional qualities, and skills through interaction with TLST managed environments and displaying those to potential employers with a great level of certainty. A digital record of this type will provide a much more accurate description of an individual's talents than a traditional college degree, allowing the potential for a much better match of skills, capabilities and contextual requirements. This capability aligns with the 2018 AETC Strategic Plan.

Finally, the TLST provides a future operational benefit through human-machine symbiosis and increased situational awareness. Pairing human exploration with machine intelligence could elevate human performance. A system that can know the person, the environment, and desired outcomes can filter the most pertinent information to the human allowing the human to act faster and make more accurate decisions. A system designed using the TLST could be used operationally across all domains of combat operations but could be specifically useful in urban combat, medical surgeries, first responders, civilian flight training or any tasks that are accomplished in complex environments that require data prioritization and ergonomic presentations to obtain a competitive advantage. The opportunity and usefulness of this technology has the potential to help humans have greater situational awareness and make better decisions faster by making better use of time and information. The fusion of mixed reality, data, and human decision making that are core to the TLST are the future of learning and combat operations. Imagine a paramedic wearing AR glasses while training how to scan an injured individual during initial triage. The device could provide feedback on the scan pattern, how long was spent on each portion of the body, all while providing the paramedic’s cognitive load and arousal state during the triage. This data could be used to help better train them on the proper triage techniques and how to better handle stressful situations. This is just one example of a future application of the TLST; there are so many more we can't even imagine. The USAF needs to invest now in theory and technology that could increase capability from the classroom to the battlefield, providing the USAF an advantage using the world's most critical resource - the human.

Conclusion

The proposed idea of the Targeted Learning System Theory (TLST) is a fusion of educational structures, learning theories, and emerging technologies that create a customized learning eco-system capable of redefining USAF education and training ways, means, and ends. The TLST was used to create the Adaptive Flight Trainer (AFT) and conduct a one-week trial with 40 subjects at Columbus, AFB to test Cognitive, Kinesthetic, and Affective learning. The average subject performance improvement was 205' (altitude control), 38 knots (airspeed control), and a 30% increase of procedural task completion with 1.5 hours of Virtual Reality Learning Environment (VRLE) training. The results provide the possibility that the TLST could reduce cost, adapt to new requirements, and create clarity from complexity for students. Learning is a decision cycle and the TLST speeds up the decision cycle to provide the learner psychological ownership and safety through iterative, student-centered, and exploratory learning. The system goes beyond just teaching facts by synthesizing underlying principles of knowledge. The experiential challenges with high fidelity feedback loops increase independent thinking and cultivate a deeper contextual understanding for the student.

There is nothing new about the TLST; it is simply a combination of technologies, structures, and learning theories fused together in a novel way. The TLST produces learning value by providing high fidelity feedback to the students. It fuses technologies to provide immersive experiences across multiple learning styles while maintaining the flexibility to adjust to the new requirements of future operating environments. The student-centered, exploratory, collaborative structure builds on components of situated and experiential learning theories informed by a constructivist approach in a connected world. Targeted learning systems that provide customized learning experiences leveraging empowering structures and emerging technologies will only continue to grow as technologies continue to mature. Technologies such as miniaturization of components (nanotechnology), wearable sensors (biosensing), exponential computing power (quantum computing), artificial intelligence (intelligent machines), block-chaining (data integrity), and immersive mixed-reality displays (VR/AR) will change how we learn, live, and act in the future. They will provide new human-machine capabilities and make current limitations obsolete.

One of the biggest finding of the TLST research study was the impact of biosensing. As discovered, the first step toward customized learning or operational human-machine symbiosis is biosensing and allowing the system to know the human. There is so much we do not know about ourselves, but from neuroscience to biology we learn more every day. The system must know the human to help the human, and the more we know, the more fidelity we can provide to smart systems to help humans make better decision faster and ultimately learn more. The ability to measure the human (bio-sensing), the environment (context), and the performance (desired outcome) in real time is becoming more powerful and practical every day with each technological maturation.

We cannot predict the future, but we can look backward and use impactful trends to inform potential outcomes. How people learn at the biological and neurological level has not changed. The current educational and training systems responsible for preparing the fabric of our nation – the sons and daughters of the United States, have also changed very little. However, the environments and the demands of human performance are significantly in flux. How we learn, why we learn, and what we learn is a question we should ask every day. The first step towards elevating human performance starts with understanding ourselves better and leveraging the right combination of structures, theories, and technologies to help humans find their untapped potential. Human capital is the USAF's most important resource and developing new ways to maximize its potential is a smart investment. The USAF has an opportunity to be the innovative organization that drives the direction of education and training in the future. As an organization it must be willing to let go of the outdated industrial models holding to truly revolutionize training and education for decades to come. Failing to change will not only leave it undermanned to meet future conflict demands but will leave Airmen underprepared to think and act in increasingly uncertain and complex situations. The TLST advocates for a smarter and more efficient use of educational structures, learning theories, and disruptive technologies to find a new approach to learning that produces equal or better results at a lower cost. It is now up to the USAF to empower future practitioners to implement these theories within their organizations to train and educate the next generation of warriors who will protect the freedom we cherish.

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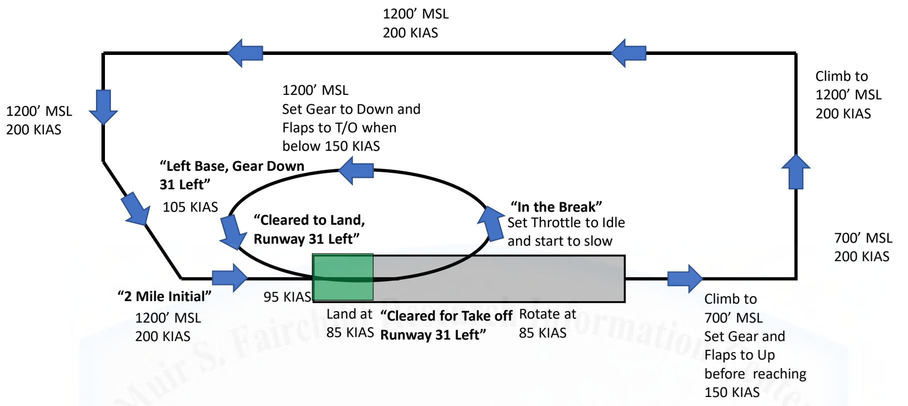
ATTACHMENTS

Attachment 1 - Task Card

TASK: You will have one opportunity to take off from the runway, fly the depicted VFR Overhead Pattern, and land. You will be expected to maintain the depicted altitude and airspeed. Finally you will be required to make five radio calls depicted in bold. Good Luck!



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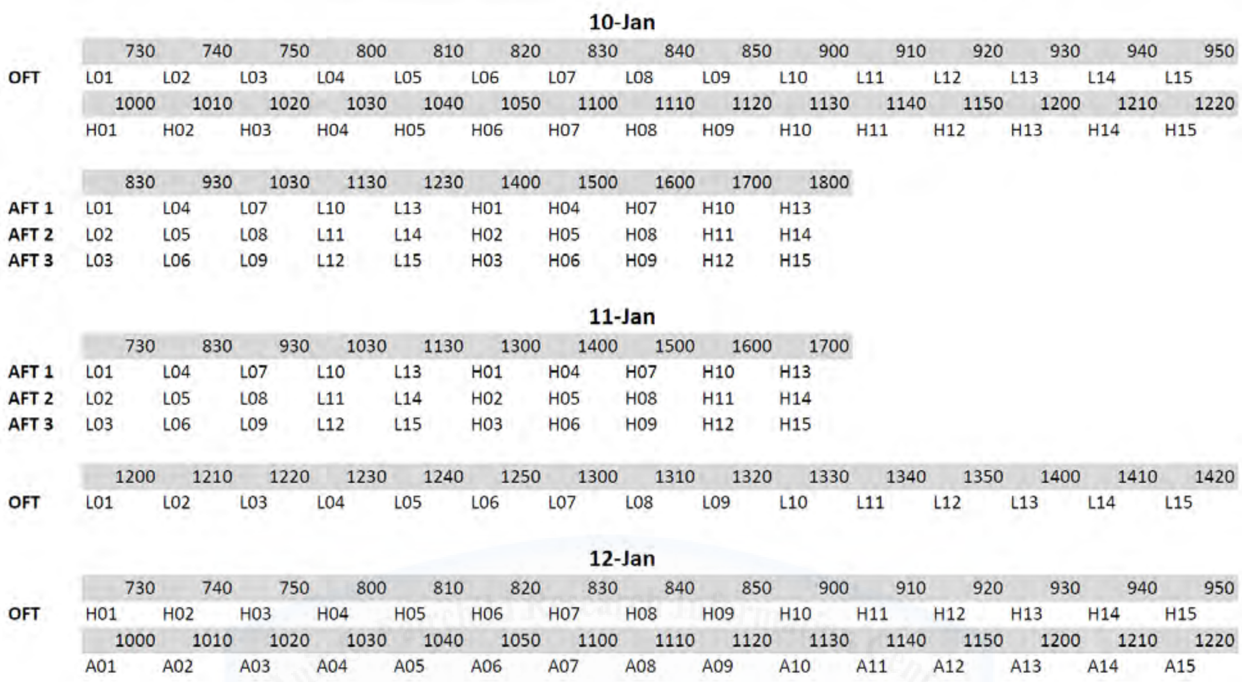
Attachment 2 - Test Schedule



10-Jan

	730	740	750	800	810	820	830	840	850	900	910	920	930	940	950
OFT	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12	L13	L14	L15
	1000	1010	1020	1030	1040	1050	1100	1110	1120	1130	1140	1150	1200	1210	1220
	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15

	830	930	1030	1130	1230	1400	1500	1600	1700	1800
AFT 1	L01	L04	L07	L10	L13	H01	H04	H07	H10	H13
AFT 2	L02	L05	L08	L11	L14	H02	H05	H08	H11	H14
AFT 3	L03	L06	L09	L12	L15	H03	H06	H09	H12	H15

11-Jan

	730	830	930	1030	1130	1300	1400	1500	1600	1700
AFT 1	L01	L04	L07	L10	L13	H01	H04	H07	H10	H13
AFT 2	L02	L05	L08	L11	L14	H02	H05	H08	H11	H14
AFT 3	L03	L06	L09	L12	L15	H03	H06	H09	H12	H15

	1200	1210	1220	1230	1240	1250	1300	1310	1320	1330	1340	1350	1400	1410	1420
OFT	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12	L13	L14	L15

12-Jan

	730	740	750	800	810	820	830	840	850	900	910	920	930	940	950
OFT	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15
	1000	1010	1020	1030	1040	1050	1100	1110	1120	1130	1140	1150	1200	1210	1220
	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	A12	A13	A14	A15

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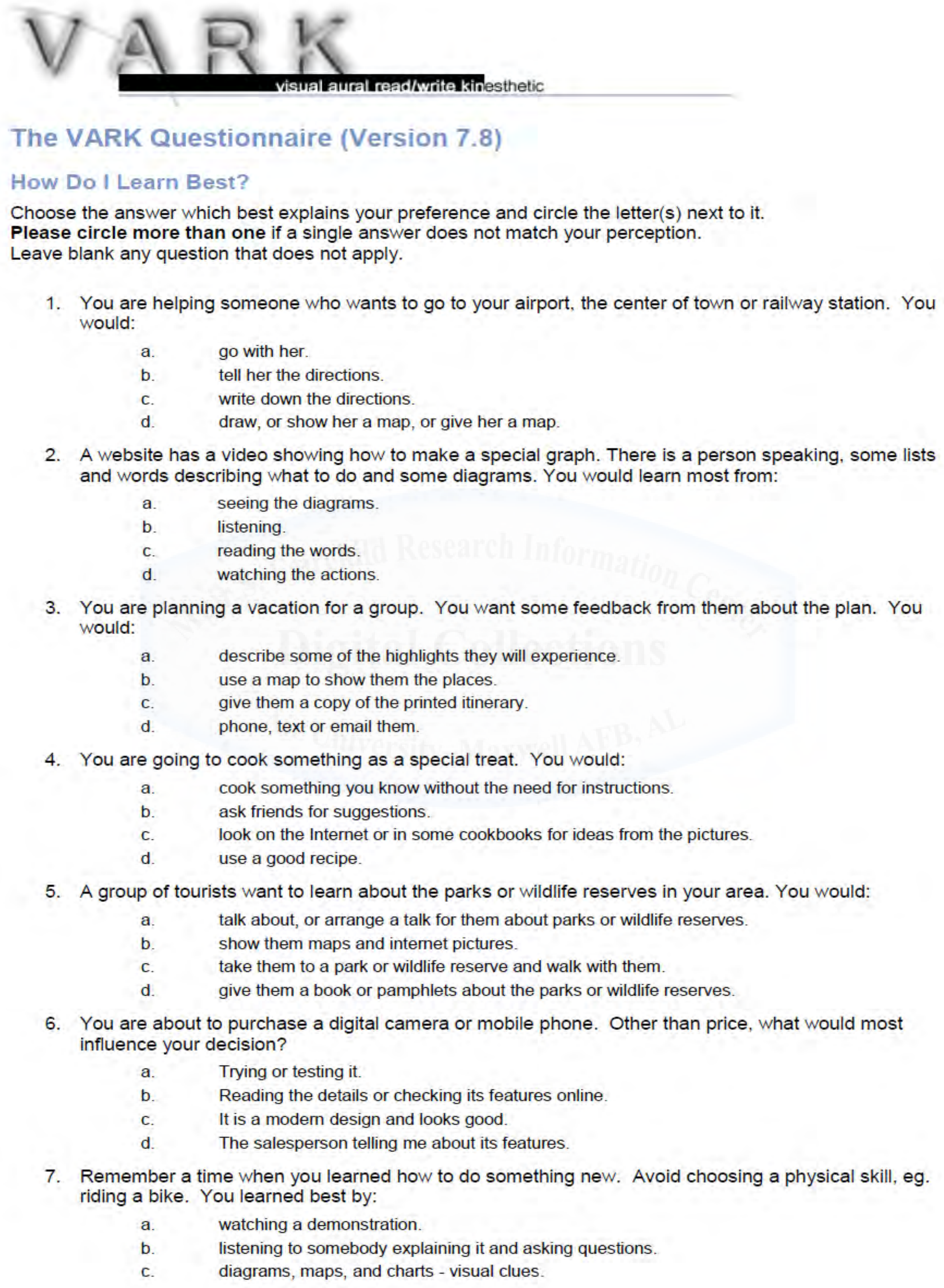
Attachment 3 - Learning Assessments



VARK
visual aural read/write kinesthetic

The VARK Questionnaire (Version 7.8)

How Do I Learn Best?

Choose the answer which best explains your preference and circle the letter(s) next to it.
Please circle more than one if a single answer does not match your perception.
Leave blank any question that does not apply.

1. You are helping someone who wants to go to your airport, the center of town or railway station. You would:
   - a. go with her.
   - b. tell her the directions.
   - c. write down the directions.
   - d. draw, or show her a map, or give her a map.
2. A website has a video showing how to make a special graph. There is a person speaking, some lists and words describing what to do and some diagrams. You would learn most from:
   - a. seeing the diagrams.
   - b. listening.
   - c. reading the words.
   - d. watching the actions.
3. You are planning a vacation for a group. You want some feedback from them about the plan. You would:
   - a. describe some of the highlights they will experience.
   - b. use a map to show them the places.
   - c. give them a copy of the printed itinerary.
   - d. phone, text or email them.
4. You are going to cook something as a special treat. You would:
   - a. cook something you know without the need for instructions.
   - b. ask friends for suggestions.
   - c. look on the Internet or in some cookbooks for ideas from the pictures.
   - d. use a good recipe.
5. A group of tourists want to learn about the parks or wildlife reserves in your area. You would:
   - a. talk about, or arrange a talk for them about parks or wildlife reserves.
   - b. show them maps and internet pictures.
   - c. take them to a park or wildlife reserve and walk with them.
   - d. give them a book or pamphlets about the parks or wildlife reserves.
6. You are about to purchase a digital camera or mobile phone. Other than price, what would most influence your decision?
   - a. Trying or testing it.
   - b. Reading the details or checking its features online.
   - c. It is a modern design and looks good.
   - d. The salesperson telling me about its features.
7. Remember a time when you learned how to do something new. Avoid choosing a physical skill, eg. riding a bike. You learned best by:
   - a. watching a demonstration.
   - b. listening to somebody explaining it and asking questions.
   - c. diagrams, maps, and charts - visual clues.

d. written instructions – e.g. a manual or book.

8. You have a problem with your heart. You would prefer that the doctor:
    a. gave you a something to read to explain what was wrong.
    b. used a plastic model to show what was wrong.
    c. described what was wrong.
    d. showed you a diagram of what was wrong.

9. You want to learn a new program, skill or game on a computer. You would:
    a. read the written instructions that came with the program.
    b. talk with people who know about the program.
    c. use the controls or keyboard.
    d. follow the diagrams in the book that came with it.

10. I like websites that have:
    a. things I can click on, shift or try.
    b. interesting design and visual features.
    c. interesting written descriptions, lists and explanations.
    d. audio channels where I can hear music, radio programs or interviews.

11. Other than price, what would most influence your decision to buy a new non-fiction book?
    a. The way it looks is appealing.
    b. Quickly reading parts of it.
    c. A friend talks about it and recommends it.
    d. It has real-life stories, experiences and examples.

12. You are using a book, CD or website to learn how to take photos with your new digital camera. You would like to have:
    a. a chance to ask questions and talk about the camera and its features.
    b. clear written instructions with lists and bullet points about what to do.
    c. diagrams showing the camera and what each part does.
    d. many examples of good and poor photos and how to improve them.

13. Do you prefer a teacher or a presenter who uses:
    a. demonstrations, models or practical sessions.
    b. question and answer, talk, group discussion, or guest speakers.
    c. handouts, books, or readings.
    d. diagrams, charts or graphs.

14. You have finished a competition or test and would like some feedback. You would like to have feedback:
    a. using examples from what you have done.
    b. using a written description of your results.
    c. from somebody who talks it through with you.
    d. using graphs showing what you had achieved.

15. You are going to choose food at a restaurant or cafe. You would:
    a. choose something that you have had there before.
    b. listen to the waiter or ask friends to recommend choices.
    c. choose from the descriptions in the menu.
    d. look at what others are eating or look at pictures of each dish.

16. You have to make an important speech at a conference or special occasion. You would:
    a. make diagrams or get graphs to help explain things.
    b. write a few key words and practice saying your speech over and over.
    c. write out your speech and learn from reading it over several times.
    d. gather many examples and stories to make the talk real and practical.

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Learning Styles Inventory Version 3.1

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Rank the endings for each sentence according to how well you think each ending describes the way you learn. Write 4 next to the sentence ending that describes how you learned best and so on down to 1 for the sentence ending that seems least like the way you learn. Be sure to rank all endings for each sentence. Do not give two endings the same number.

4 = Most Like You

1 = Least Like You

1. When I learn: ____ I am happy. ____ I like to think about ideas. ____ I like to be doing things. ____ I like to watch listen.	7. I learn best from: ____ Observation ____ Personal Relationships ____ Rational Theories ____ A chance to try out and practice
2. I learn best when: ____ I like to deal with my feelings ____ I like to think about idea. ____ I like to be doing things. ____ I like to watch and listen	8. When I learn: ____ I like to see results from my work ____ I like ideas and theories ____ I take my time before acting ____ I feel personally involved in things
3. When I am learning: ____ I tend to reason things out. ____ I am responsible about things. ____ I am quiet and reserved ____ I have strong feelings and reactions	9. I learn best when: ____ I rely on my observations ____ I rely on my feelings ____ I can try things out for myself ____ I rely on my idea
4. I learn by: ____ Feeling ____ Doing ____ Watching ____ Thinking	10. When I am learning: ____ I am a reserved person ____ I am accepting person ____ I am responsible person ____ I am rational person
5. When I learn: ____ I am open to new experiences ____ I look at all sides of issues ____ I like to analyze things, break them down into their parts ____ I like to try things out	11. When I learn: ____ I get involved ____ I like to observe ____ I evaluate things ____ I like to be active
6. When I am learning: ____ I am an observing person ____ I am an active person ____ I am intuitive person ____ I am a logical person	12. I learn best when: ____ I analyze idea ____ I am receptive and open minded ____ I am careful ____ I am practical

Attachment 4 - Affective Assessments

Pre-Test Assessment

Assigned Callsign:________________

Age: ____ Sex: ____ Glasses/Contact Lenses (Y/N): ____

Flight Experience (Aircraft/Hours): ____

Education level: HS, Some College, Associate, Bachelors, Masters, PHD

Rate your immersive console, computer, or Virtual Reality gaming degree of usage.

0	1	2	3	4	5
None	Very Rarely	Rarely	Occasionally	Frequently	Very Frequently

What is your preference for learning how to accomplish a new task (rank order 1-5)?

Watching a Video ____ Audio Explanation ____ Reading from a trusted source ____

Doing it in the real world ____ Playing a simulation game_______

Please rate your level of agreement or disagreement with the below statements (circle one):

I am confident that I can successfully execute the depicted VFR overhead pattern.

0	1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I am anxious about my participation in the upcoming simulator evaluation.

0	1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I am knowledgeable of the following T-6A Texan II components (as a group): Airspeed Indicator, Altimeter, Angle of Attack Gauge?, HSI?, Landing Gear and Flaps Controls and Indicators, Aircraft Airspeed Limitations.

0	1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

`

I am knowledgeable about VFR overhead pattern procedures.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I understand how the Throttle, Control Stick, and Rudder interact to maneuver the aircraft.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe that training in the Virtual Reality Adaptive Flight Trainer will improve my performance on the depicted VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Adaptive Flight Trainer will effectively simulate the physical act of flying (discounting the "seat of your pants" and lack of G-forces).

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Virtual Reality environment will effectively simulate the visual act of flying a VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Adaptive Flight Trainer will effectively immerse me in the flight environment to the point that I will forget I am in a simulator (i.e. suspended my disbelief).

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

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I believe the Adaptive Flight Trainer could be used to effectively conduct aspects of undergraduate pilot training.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Post-Training Assessment

Please rate your level of agreement or disagreement with the below statements (circle one):

I am confident that I can successfully execute the depicted VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I am anxious about my participation in the upcoming simulator evaluation.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I am knowledgeable of the following T-6A Texan II components as a group: Airspeed Indicator, Altimeter, Angle of Attack Gauge?, HSI?, Landing Gear and Flaps Controls and Indicators, Aircraft Airspeed Limitations.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I am knowledgeable about VFR overhead pattern procedures?

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I understand how the Throttle, Control Stick, and Rudder interact to maneuver the aircraft.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe that completing the Virtual Reality training program will improve my performance on the depicted task?

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Adaptive Flight Trainer effectively simulated the physical act of flying (discounting the “seat of your pants” and lack of G-forces).

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Virtual Reality environment effectively simulated the visual act of flying a VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Adaptive Flight Trainer effectively immersed me in the flight environment to the point that I forgot I was in a simulator (i.e. suspended my disbelief).

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Adaptive Flight Trainer could be used to effectively conduct aspects of undergraduate pilot training.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Post Test Assessment

Please rate your level of agreement or disagreement with the below statements (circle one):

I effectively learned how to fly the T-6 Texan II in a VFR overhead pattern to accomplish the assigned tasked.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

`

I believe the Adaptive Flight Trainer aided my learning with respect to flying the VFR overhead pattern.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

I believe the Adaptive Flight Trainer could be used to effectively conduct aspects of undergraduate pilot training.

0	**1**	**2**	**3**	**4**	**5**
Strongly Disagree	Somewhat Disagree	Slightly Disagree	Slightly Agree	Somewhat Agree	Strongly Agree

Did you at any time experience any motion sickness in the VR environment? **Y / N**

If Yes, was it **continuous** or **occasional**?

Did it affect your ability to learn in the VR environment? **Y / N**

Please provide any additional feedback you may have for the team in the space provided below, you may continue onto the back of the page if needed.

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Attachment 5 - Task Instructions

Day 1 Welcome Instructions

Thank you for volunteering to participate in the Targeted Learning System and Adaptive Flight Trainer research study. The goal for you this study is to perform to your maximum potential a given task in a T-6A OFT simulator. You will be given detailed instructions during each phase of the study, and we ask that you please comply with all guidance to ensure standardization and the integrity of the control variables. This study is voluntary and you may leave at any time, but know that your participation is greatly appreciated and the data collected will help shape conversations and future research about learning and training in the USAF.

The study consists of two learning assessment surveys as well as a Pre-Test, Post-Training, and Post-Test Assessment. You will perform tasks during two T-6 OFT simulator flights and during two 1-hour Virtual Reality flight-training sessions. You will shortly be given more information regarding the purpose of the study and be introduced to the research team. Before you leave today ensure you have turned in both learning assessments, know your study assigned Callsign, and confirmed your schedule for tomorrow.

Please do not try to game the system or worry about what measurements are taken. Just do your best to fly the best airplane you can.

Good Luck!

Pre-Test Instructions

Please complete the Pre-Test Assessment. Please complete all demographic information to include Callsign, age, sex, contact lenses/glasses, flight experience, and education level and answer all questions. Please turn in completed assessment to observer. You have 5 minutes to complete the assessments.

Base Line OFT Instructions

This task card explains the flight profile you are requested to fly in the OFT. You will have 10 minutes to review this card. At the end of 10 minutes, the task card will be taken away, you will not be able to reference it again, and you may not take any notes. You may not ask any questions of the observers.

Five minutes prior to your scheduled test time, an escort will take the task card and bring you down to the simulator to await your test. When instructed please allow the observers to expeditiously help you into the simulator. The simulator will be set up with engines running on Runway 31L at Columbus AFB. All switches will be set in the correct position.

When in the seat please close your eyes, relax your body, and take 10 deep breaths and attempt to clear your mind. When you are in place or at your scheduled start time you will hear **"[your callsign], clear for take-off Runway 31L"**. This is the start of the test profile.

Upon completion of the test profile, please follow the instructions of the observers to exit the simulator and return to the simulator staging area to confirm your Virtual Reality training times.

Good Luck!

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Pre-Virtual Reality (VR) Instructions

You are about to begin your VR training sessions. You will have 2 session up to 1 hour each. You can train in the environment for as long as you would like up to your 1-hour limit, and can complete as many pattern sorties as you want.

Your goal is to train to improve your performance on the profile executed in the simulator and depicted on the task card. You may review and keep this task card throughout your training session, but it must be returned to the observer at the conclusion of your hour block. A virtual training environment has been created to help guide your learning in the virtual environment. The VR training consist of three levels and you must pass each level once before moving to the next level. You control your training and how much time you spend in each, however the cues in the first two levels will not be available in the OFT for your final event. Your observer will help you load scenarios and manage the computer systems, but can provide no other assistance.

Upon arrival at your assigned prototype your observer will provide instructions on donning and doffing the VR equipment, which throttle switches will operate your landing gear and flaps, and orienting your position to the environment to ensure visual accuracy. Do not ask any questions of the observers, but do provide feedback if the environment does not look correct (ex. You appear to be sitting outside the aircraft).

Before asking the observer to un-pause the environment to start your sortie, please close your eyes, relax your body, take 10 deep breaths, and try to clear your mind. If at any time you feel uncomfortable, ask the observer to pause the simulation so we can address your concerns. The sortie will start when the observer states **“[your callsign], clear for take-off Runway 31L”**.

After completion of the pattern the observer will pause the environment and a feedback tool is available at the computer station to show your performance, cognitive load, and eye tracking. The decoder document explains what each quadrant of the feedback tool is presenting. You may keep and reference the decoder for the duration of your training time, but it must be returned to the observer at the end of your hour block. The observer will load your last sortie into the feedback tool, will provide you feedback on radio calls and configuration, but will not provide feedback on your flight performance or aid you in interpreting the feedback tool.

When you are ready to continue training the observer will load your requested virtual environment level. Remember you must pass a level once before progressing to a higher level. You can always revert to a lower level if you would like. Please remember to relax your body, take 10 deep breaths, and try to clear your mind before asking the observer to un-pause and start the sortie.

Upon completion of your VR training session please report to the observer to confirm your next training time. You must utilize the same prototype for each session. Following the second training session, you will be required to take a short post-training assessment.

Good Luck!

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VR Post Sortie Feedback Verbiage

“You missed **X** radio calls, refer to your Task Card for further guidance.”

“You failed to configure properly, refer to your Task Card for further guidance.”

Post-Test Instructions

This is your final event, thank you for your participation and efforts in this study.

This task card explains the flight profile you are requested to fly in the OFT. At the end of 10 minutes, the task card will be taken away, you will not be able to reference it again, and you may not take any notes. You may not ask any questions of the observers.

Five minutes prior to your scheduled test time, an escort will take the task card and bring you down to the simulator to await your test. When instructed please allow the observers to expeditiously help you into the simulator. The simulator will be set up with engines running on Runway 31L at Columbus AFB. All switches will be set in the correct position.

When in the seat please close your eyes, relax your body, and take 10 deep breaths and attempt to clear your mind. When you are in place or at your scheduled start time you will hear **“[your callsign], clear for take-off Runway 31L”**. This is the start of the test profile.

Upon completion of the test profile, please follow the instructions of the observers to exit the simulator and return to the simulator staging area to complete a Post-Test assessment. Good Luck!

Post Completion of Study

Thank you for your participation in the Targeted Learning System and Adaptive Flight Training research study. Please complete the Pre-Test Assessment. In addition to the required questions, we welcome any feedback you have on the adaptive flight trainer, your experience as a student in the virtual reality environment, and any thoughts you have on improving learning through the use of technology.

The goal of this study was to measure cognitive and kinesthetic flight skill transference from a prototype Virtual Reality trainer to a current flight simulator. The study also utilized artificial intelligence to identify determinate variables in successful performance. This was accomplished utilizing cutting-edge technology and virtual learning environments developed based off the most recent research in the fields of adult learning and virtual environments.

If you desire we can present you with a radar plot and discuss your performance throughout the virtual training flights. Unfortunately we will not have the data of your performance in the OFT simulator for a few weeks. If you would like to know the results of your OFT performance or would like to see a final report please let the observer know and provide your email.

The results of this study will be used to draw correlations and trends that further the Targeted Learning System Theory and its applications to USAF training and learning across multiple disciplines besides pilot training. This research will be presented at Air University, to the civilian industry in the form of publishing in an academic journal and given directly to the AETC Commander to drive future USAF education and training innovation.

Thank you again for your participation in the study and best of luck in the future.

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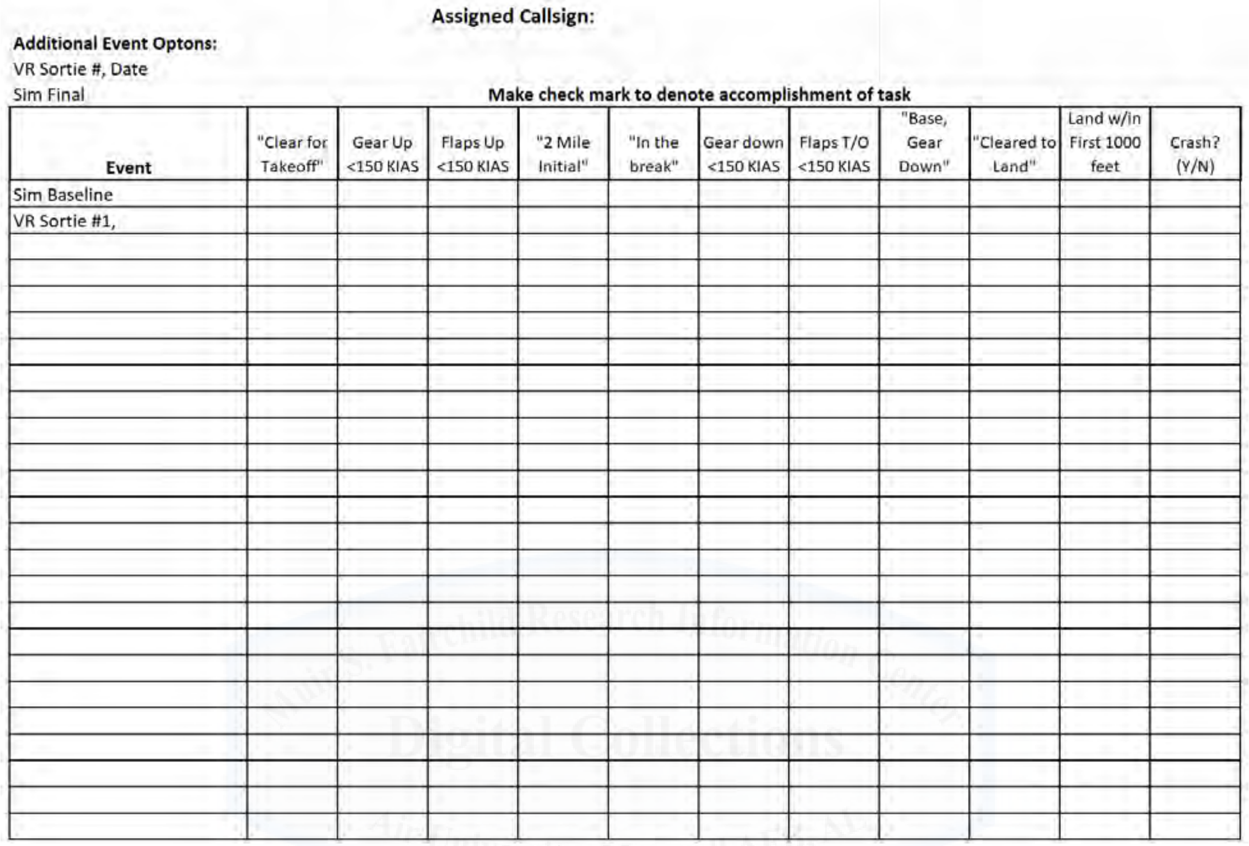
Attachment 6 - Manual Task Tracker



Assigned Callsign:

Additional Event Optons:
VR Sortie #, Date
Sim Final

Make check mark to denote accomplishment of task

Event	"Clear for Takeoff"	Gear Up <150 KIAS	Flaps Up <150 KIAS	"2 Mile Initial"	"In the break"	Gear down <150 KIAS	Flaps T/O <150 KIAS	"Base, Gear Down"	"Cleared to Land"	Land w/in First 1000 feet	Crash? (Y/N)
Sim Baseline											
VR Sortie #1,											

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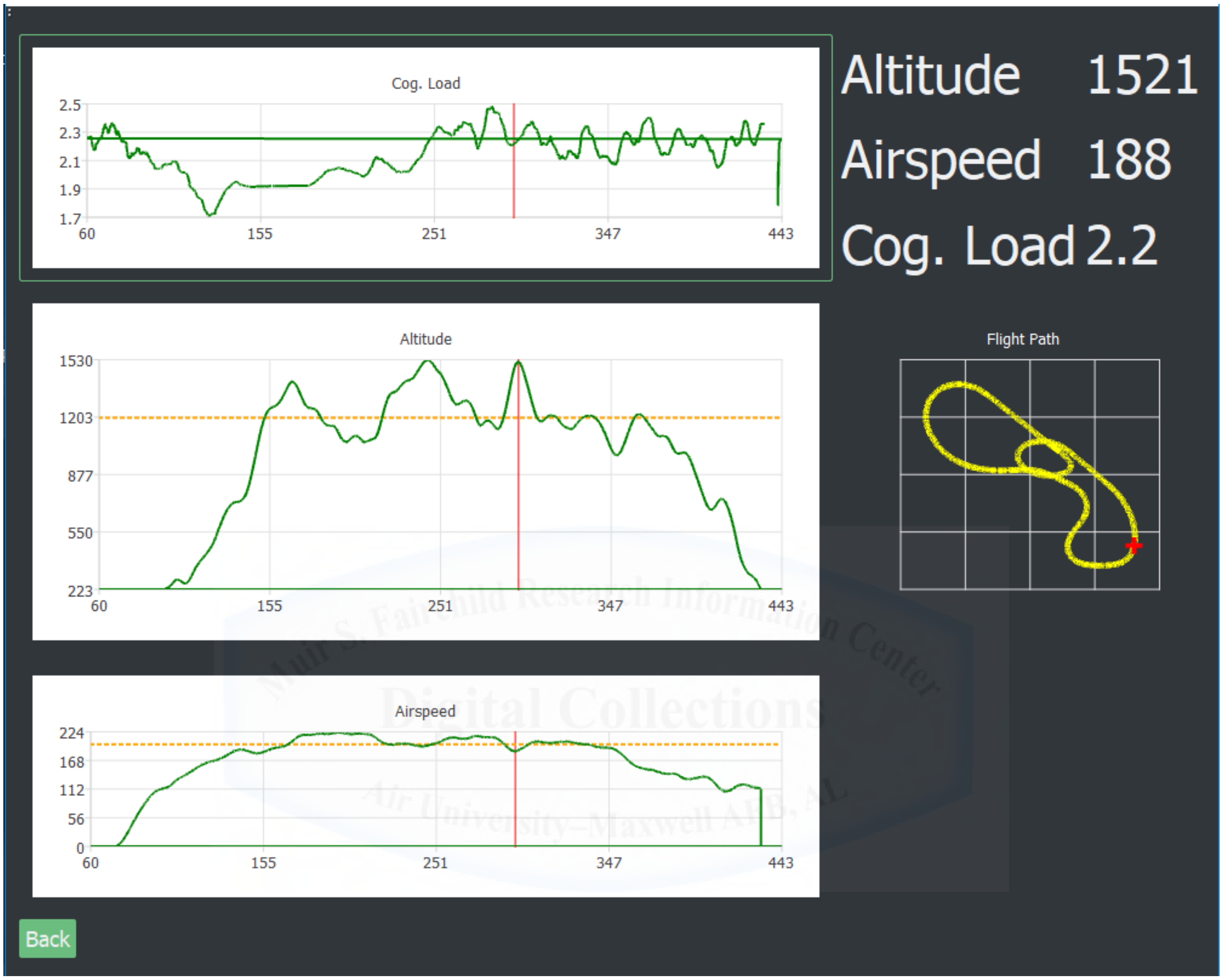
Attachment 7 - Post VR Sortie Debrief Tool



Altitude 1521

Airspeed 188

Cog. Load 2.2

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Annotated Bibliography

Robert Coughlan, *Dr. Edward Teller's Magnificent Obsession*, LIFE magazine (6 September 1954)

> This is a Life magazine article about the "Story behind the H-bomb is one of a dedicated, patriotic man overcoming high-level opposition." This article was used to quote Niels Bohr dictum about failure and success.

Rickover, Hyman G., and Edward R. Murrow. *Education and Freedom*. New York: Dutton, 1961, 38.

> This book explores the power of education and its impact on national defense. Hyman Rickover was an Admiral focusing on the technological changes occurring in the world with regard to nuclear capabilities. He focuses on the development of human capital that can use lead time effectively. Lead time is the "time which elapses between conception of a new idea, its development, and finally its fruition in the completed new article rolling from production lines – is the factor that more than any other is likely to win the next war for the nation which succeeds in reducing it significantly below that of its competitor." He writes about the development of human potential as the deciding factor in the future wars. The advocates the importance of education to the nation to maximize human potential in the name of military strength as a "vital national objective."

Lieutenant General Gina M. Grosso, *Military Pilot Shortage,* House Armed Service Committee, March 29 2017.

> This article is coverage of congressional testimony from senior military leaders on the current USAF pilot shortage. It discusses the probable causes, the number of pilots mandated, the number of pilots making up the shortage, and the current strategies of the USAF to fix the problem. It mentions the limited return on investments in the current USAF structures - "future increases in throughput will require additional manpower, infrastructure, operations and maintenance resources."

The Institute for the Study of Human Knowledge and The Human Journey, *Education: Our Challenge Today,* accessed 6 April 2018, https://www.humanjourney.us/health-and-education-in-the-modern-world/education-for-a-changing-world-present-day-challenge/.

> This article was written by Institute for the Study of Human Knowledge. "The Institute for the Study of Human Knowledge (ISHK) was incorporated in 1969 as a 501c(3) charitable educational organization dedicated to cross-cultural understanding and to bringing important research on human nature to the general public. ISHK takes a multi-disciplinary approach to the questions of who we are, where we came from, and what we might become. Our programs and publications highlight contributions from contemporary psychology, education, anthropology, medicine, evolutionary biology, neuroscience, and ecology — as well as from traditional systems of knowledge and learning with ancient roots." In this article looks at mass education across the globe and makes recommendations to improve our current system by looking at how people learn and how currents education systems fall short.

Sharon Hartin Iorio, *"School Reform: Past, Present and Future," School Reform Strategies,* (Oxford University, July 2011), 4.

> "This paper briefly reviews the history of U.S. school reform movements and present issues currently being discussed as reform initiatives. More specifically, the paper will address the following: student learning gains and student assessment, education for diversity, curriculum development, and university preparation for pre-service teachers. The paper will address these current concerns by focusing on the transformation of pre-baccalaureate teacher education through a discussion of the efficacy of the Professional Development School model for experiential learning coupled with changes in teacher education pedagogy. Offered as an example will be the implementation of the Wichita Teacher Quality Partnership between Wichita State University (approximate total enrollment 14,000) and the Wichita Public School system—(the 50th largest public school district in the United States and the only school system in the state of Kansas to be federally designated as a high-need urban school district). This partnership is developed from a U.S. Department of Education five-year grant currently in its second year. The paper will end with recommendations for moving forward in teacher education."

Arthur, Brian W. 2009. The nature of technology: What it is and how it evolves. New York: Free Press. Pg29

> This book is a philosophical look at technology and focuses on how technology evolves. It seeks to answer the question of how humans use technology to impact the world. It attempts to answer how new technological discoveries are found and how technology changes.

Khan, Salman. The one world schoolhouse: education reimagined. London: Hodder & Stoughton, 2012.

> "Khan presents his vision on how both students and teachers are being bound by a broken top-down model invented in Prussia two centuries ago, why technology will make classrooms more human and teachers more important, how and why we can afford to pay educators the same as other professionals, How we can bring creativity and true human interactivity back to learning, why we should be very optimistic about the future of learning."

John Boli, Francisco Ramirez, and John Meyer, "Explaining the Origins and Expansion of Mass Education," *The University of Chicago Press Journals, Vol. 29, No.2 (May 1985), 147, 149.*

> This article focuses on and argues that "theories of mass education that emphasize processes of differentiation or the reproduction of inequalities ignore the universal and institutional character of mass education. A theoretical framework emphasizing individualism and the rationalization of individual and collective authority better explains the relationship of mass education to national objectives in a competitive world."

Dr. John Kotter, Exponential Rate of Change, Cambridge, MA, July 19, 2011, https://www.forbes.com/sites/johnkotter/2011/07/19/can-you-handle-an-exponential-rate-of-change/#18b715d44eb0

> This is a manuscript from Dr. John Kotter who is a professor at the Harvard Business School. He talks about the exponential change he witnesses and measures in the world and how revolutionary products today are made obsolete in just a few years.

Chengtu Hsieh, Melissa Mache, and Duane Knudson, “Does student learning style affect performance on different formats of biomechanics examinations?” *Sport Biomechanics,* Vol. 11, No. 1 (March 2012).

Examines if the format of the assessment tool matched to a learner’s preference will you get a more accurate assessment of learning. To start students were given VARK Learning style inventory and self-reported learning style surveys. 87% of students had a single preferred learning style with K=53%, R=20%, A=18%, V=9%. Only 47% of students matched their most preferred learning style to the results of the VARK assessment. Students were given a test with either text only questions and answers or one with text and pictures. There is no difference in performance based off assessed or self-reported learning styles and test performance. Students demonstrated learning regardless of getting the test in their preferred mode or not.

Michael Prithishkumar, “Understanding your student: Using the VARK model,” *Journal of Postgraduate Medicine,* Vol. 60, No. 2 (April 2014).

Discusses key factors that play a role in learning to include: a student's interest, a student's intrinsic/extrinsic motivation, individual principles, active student participation, affective domain of the student and preferred learning style. Learning style inventories are information-processing models that aim to identify a student's preferred intellectual approach in assimilating and processing information. Provides a summary of each learning style. Learning styles can change, especially since our early learning is predominated by didactic lecture and getting out of that model can help a student develop other styles.

Chen Jen Chen, Seong Chong Toh, and Wan Mohd Fauzy Wan Ismail, “Are Learning Styles Relevant to Virtual Reality,” *Journal of Research on Technology in Education,* Vol. 38, No.2 (Winter 2005).

This article examines the effect of different learning styles in VR. A key finding is that regardless of learning styles, guided exploration mode had the greatest benefit. The authors reference back to Kolb's experiential learning cycle and point out that VR could support all four of Kolb's learning characteristics. They conducted the test with students who did not yet take a driver’s course. They gave a VR pre/post test to see the students understanding of traffic rules and signs. The independent variables were VR Guided, VR unguided, and non-VR. There was a significant difference in the gains from pre to post-test for all assimilator learners. VR guided was significantly higher than the other two, with no real significance in gain between VR non-guided and no VR. Same goes for the accommodator learners. Comparing VR guided gains between assimilator and accommodator learners there was no significant differences. This shows the effect of gains was not on the learning styles, but on the learning mode. Guided exploration worked for the more passive/abstract assimilator and the more active/concrete accommodator by covering all the bases in one environment.

If you only allow exploration the learner has an extraneous cognitive load because of the effort to stay oriented. If intrinsic cognitive load is high (due to a difficult domain or concept of knowledge) and extraneous cognitive load is high learning may not occur. It's important to manage the extraneous cognitive load when first introducing new topics until the intrinsic cognitive load is lowered. If you provide info about the status of system variables it makes the system more transparent and helps reduce the cognitive load. Big problem with the majority of research in virtual environments is that it is technology driven, not taking the human factor into account.

Hsiu-Mei Huang, Ulrich Rauch, and Shu-Sheng Liaw, “Investigating Learners attitudes toward virtual reality learning environments: Based on a constructivists approach,” *Computers and Education,* Vol. 55 (2010).

Defines VR as I^3 (Immersion, Interaction, Imagination) with two types of immersion, mental and physical/sensory. The constructivist approach to education says that learners take an active role in the learning. Education should be experimental and experiential. The authors provide an educational basis for how we design our learning environment. Situated learning is how to execute Dewey's theories. VR allows users to interact in real time, offers rich perceptual cues and multimodal feedback enabling the easy transfer of VR learning into real-world skills while allowing for deeper learning. Case study 1 shows that to a statistically significant factor all I^3 factors contributed to the dependent variable of student motivation, with immersion having a higher contribution and all three were predictors of enhanced problem-solving capabilities with interaction having more prediction.

Zahira Merchant, Ernest T. Goetz, Lauren Cifuentes, Wendy Keeney-Kennicutt, and Trina J. Davis, “Effectiveness of VR based instruction on student learning outcomes in k-12 and higher education: a meta-analysis,” *Computers and Education*, Vol. 70 (2014).

This study conducted a meta-analysis of other studies to determine the effectiveness of VR instruction on student learning outcomes. The authors defined sims, games and VR environments. Previous work indicated that students perform better when given guidance in practice modes and that students perform better when they control navigation. What the meta-analysis found was that games and virtual worlds are suitable for all three learning outcomes (knowledge-based, abilities-based, or skill-based). VR assessments in games also showed a retention level beyond short term learning. Overall VR based learning is quite effective.

Andrea Stevenson Won, Brian Perone, Michelle Friend, and Jeremy N. Bailenson, “Identifying Anxiety through tracked head movements in a virtual classroom” *Cyberpyschology, Behavior, and Social Networking* Vol. 19, No.6 (2016).

Interesting study about anxiety in virtual environments. The authors used head tracking to find a standard deviation in the Yaw axis to show that in unstructured portions of the virtual "class" students were scanning the other students. Their questionnaire showed that students were anxious during their time in the virtual classroom. The amazing thing was that the "other students" were digital agents, the fact that they weren't real didn't matter because the subjects felt those agents were socially present.

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Jerome Rodrigues, Helene Sauzeon, Gregory Wallet, and Bernard N'Kaoua, "Transfer of Spatial Knowledge from Virtual to Real Environment: Effect of active/passive learning depending on a test-retest procedure and the type of retrieval tests," *Journal of CyberTherapy and Rehabilitation* Vol 3, No.3 (Fall 2010).

This study indicates that good spatial knowledge transfers from the Virtual Reality environment (VE) to the real world (RW). Peruch and Corazzini (2003) suggest that the environment needs to replicate relevant characteristics of the real world. There is no definitive study showing the superiority of active rather than passive exploration leading to better spatial transfer. It could be the tests used that effects the outcomes. Wayfinding tasks, particularly of complex routes lends itself more to active exploration. Subjects were broken into groups to test VE vs RW, and active vs passive to evaluate spatial knowledge transfer at the 48 hours and 7-day marks. They demonstrated that good spatial knowledge transfers from VE to RW and how you test the subjects effects the results.

Andrzej Grabowski and Jaroslaw Jankowski, **"**Virtual reality=based pilot traning for underground coal miners," *Safety Science*, Vol. 72 (2015).

This study used VR to train coal miners in mining tasks. The subjects had great expertise in training which makes their remarks and opinions useful. They used a training scenario related to blasting work because it is particularly dangerous. They used wireless VR gloves and handheld controllers. In all cases subjects that trained in the highly immersive virtual environment performed better. A vision-based tracking system allowed for a more natural movement and intuitive grasping and manipulation of objects. One problem was a lack of tactile feedback. Three months later, an additional questionnaire showed that the subjects thought the training usefulness was very high and had a positive effect on their own sense of confidence and knowledge.

K. Richard Ridderinkhof and Marcel Brass, "How kinesthetic Motor Imagery works: A predictive-processing theory of visualization in sports and motor expertise," *Journal of Physiology – Paris,* Vol. 109 (2015).

This article shows the value of Motor Imagery (MI) through a literature review. MI is a cognitive ability allowing an individual to perform and experience motor actions in the mind. It is prevalent in elite athletes. You have first person and third person perspective, but you usually combine them. Functional equivalence is the similarity between imagined and actual performance. Maximum effectiveness of the subject occurs if you can match actual performance in the aspects of physical, environment, task, timing, learning emotion, and perspective. Patterns of Neural activity of overt motor performance are mirrored during KMI because they have overlapping neural circuits. It is more like the activation that occurs during preparatory planning stages. Concludes with a case study on goal keepers studying penalty kicker's feetand body position to better learn the motor skills during live PKs when guessing the shot path.

Jeremy Bailenson, Kayur Patel, Alexia Nielsen, Ruzena Bajsky, Sang-Hack Jung, and Gregorij Kurillo, “The effect of interactivity on learning physical actions in virtual reality,” *Media Psychology*, Vol. 11, No.3 (2008).

This study looks at the effects of interactivity and physical learning in VR and provides background showing VR’s use for kinesthetic learning. Digital tech has moved audiences from passive receivers to active users, and VR affords more interactivity than any other medium. Two important features of VR studies are that you can track movements to see where user is focusing attention, and the designer has control of user's experience and can alter the environment to fit experimental goals. VR has been used in physical rehab because it creates a more interactive rehab and increases patient motivation. It also provides feedback on movements to reduce patient errors. The authors completed a study using Tai Chi movements with VR and only video. Students subjectively reported that they learned better, enjoyed the experience more, and thought the teacher was more credible in VR vice video. This was only in the self-report though not the objective review of the movements (behavioral data). This could be because you must provide more feedback to improve interactivity for kinesthetic learning. When they increased opportunities for feedback they saw better objective learning.

Constantinos Loukas, Nikolaos Nikiteas, Dimitrios Schizas, Vasileios Lahanas, and Evangelos Georgiou, “A head to head comparison between virtual reality and physical reality simulation for basic skills acquisition,” *Surgical Endoscopy*, Vol. 26 (2012).

Tested laparoscopic skills (LS) with VR vs Standard Video simulators (peg transfer, cutting, knot-tying). LS requires acquisition of psychomotor skills that are different than those needed for open surgery. The traditional training method of see, do, teach doesn't work. LS needs to be proficiency based rather than time based. Both devices enhance performance, and skills learned in one modality transfer to the others in all tasks, even knot-tying which is challenging to reproduce in the VR. A key to this was force feedback being incorporated. Currently the biggest limitation in VR simulators is the lack of haptic feedback. In this case for knot-tying the VR provided sufficient training for knot tying, but not to the level of proficiency of the Visual Trainer, likely because of the challenge in simulating the environment.

Ann Sofia Skou Thomsen, **“**Intra-ocular Surgery - assessment and transfer of skills using a virtual reality-based simulator,” *Acta Ophthamologica,* Vol. 95 (Sep 2017).

Performance in the EyeSi simulator for intraocular surgery highly correlates to real life surgical performance (i.e. experts in real life perform to the same level in the sim). There was a high variance between individuals, specifically the intermediate surgeons, probably because they were experimenting with new techniques. There is an impact to proficiency-based training vice the time-based method with novices showing a 32% improvement. VR training is just as effective as training on silicone or patients, but VR was faster.

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Anat Mirelman, Inbal Maidan, Talia Herman, Judith E. Deustch, Nir Giladi, and Jeffrey M. Hausdorff, "Virtual reality for gait training: can it induce motor learning to enhance complex walk and reduce fall risk in patients with Parkinson's disease?" *J Gerontol A Biol Sci Med Sci,* Vol. 66A (Feb 2011).

This is a pilot study with no control group. This study used VR to conduct gait training in patients with Parkinson's disease. VR has the capability to provide visual, auditory and haptic inputs, this multisensory feedback enhances motor learning through problem solving. Patients would walk on a treadmill in VR and negotiate two obstacles. This required them to process multiple stimuli and challenged them to make decision on two planes. These decisions were made more difficult by adjusting lighting, adding moving obstacles, and adjusting the frequency and size of the objects. Dual task gait speed increased 17.4% and gains in gait speed and stride length for dual tasks when conducted on the treadmill with VR saw significant gains over treadmill alone. Furthermore, after training patients made 31% less mistakes on cognitive tasks. They also saw improvements in tasks that share properties but were not specifically trained for (four square step test and trail making test). VR adds value to dual task training because patients learned to perform under multimodal conditions (with distractors) and divide their attention. The cognitive requirements created additional learning opportunities and fostered new movement behaviors as seen in the improvement of other tasks.

Chris Fowler, **"**Virtual Reality and Learning: Where is the pedagogy?" *British Journal of Educational Technology,* Vol. 46, No.2 (2015).

Overall this advocates for taking a pedagogical approach to Virtual Learning Environment (VLE) design and gives some models that help do that. The three defining characteristics of 3D VE are the illusion of three dimensions, smooth temporal and physical changes, and a high level of interactivity. The representational fidelity and learner interaction combine to create a psychological experience described as a sense of being there or sense of presence or even a sense of being there together for groups. Do VE actually have any learning benefits specifically in the five benefits of spatial knowledge representation, experiential learning, engagement, contextual learning and collaborative learning? Many people focus purely on the technological side through fidelity and interaction. An immersive system will lead to a "presence", so the design should focus on making the environment immersive to bridge the technological, psychological and pedagogical experiences. Mayes Fowler framework: First Learners encounter explanation of description that provides an opportunity for a new concept to be created (Primary Courseware). Second they start to explore, manipulate, ask questions, this construction stage requires interactivity (Secondary courseware, because the immersion is in the task not the representation). Third is dialogue allowing the learner to test their emerging understanding through some kind of interaction (Tertiary courseware). VLEs need to create new learning experiences, not just emulate old ones or we'll end up with a very nice virtual classroom, just like a real one.

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Joseph Psotka, **“**Educational Games and VR as Disruptive Technologies,” *Educational Technology and Society,* Vol. 16, No.2 (2013).

Advocates for greater games and VR and learning because it has the power to motivated learners. Motivation is an essential part of the pedagogy in a system of instruction, and VR does this with challenge, social interaction, peer feedback, and the instantiation of local goals as well as immersion and presence. VR embodies abstract concepts in concrete experiences. You must take the learner into account when developing systems to include age, gender, culture, and learning preferences. Advocates for modular learning with nationwide certifications based on standardized assessments that let students drive their education.